CHAPTER 1

INTRODUCTION

1.1 GENERAL

Looking around the world, concrete structures are seen everywhere. From homes to office buildings to highways, using concrete as a construction material actually helps to protect our natural resources and affords unique benefits to consumers. The importance of concrete in modern society can not be underestimated. As a reliable and versatile product for centuries, concrete paves the way towards an environmentally secure future for successive generations here on earth. Concrete is supposed to be in tune with the environment.

The ability of concrete to withstand the action of water without serious deterioration makes it an ideal material for building structures to control, store and transport water. The ease with which structural concrete elements can be formed into a variety of shapes and sizes is one of the reasons for concrete’s success. This is because freshly made concrete is of a plastic consistency, which permits the material to flow into prefabricated formwork. After a number of hours, the formwork can be removed for reuse when the concrete solidifies and hardens to a strong mass. It is usually the cheapest and the most readily available material on the job. Further commendable characteristics of concrete are waste minimization and long life. Whether cast in place or precast, concrete can be used on an as-needed basis. Concrete is a
durable material that actually gains strength over time. It conserves resources by reducing maintenance and need for reconstruction (Ramachandran 2001).

1.2 REINFORCED CEMENT CONCRETE

Plain concrete has relatively high compressive strength but significantly lower tensile strength. Hence any appreciable tension will lead to rupture and consequent failure. For this reason, the use of plain concrete is limited to a structural member subjected to bending or direct tensile action. When reinforcement like steel bars is incorporated into concrete, a reinforced concrete section is created. Reinforced concrete is a concrete in which reinforcement bars have been incorporated to strengthen the material that would otherwise be brittle. These reinforced concrete sections are much more efficient in carrying tensile forces due to bending or direct tension than a plain concrete section with the same dimensions. The general rule is that concrete is strong in compression and steel is strong in tension.

There are three physical characteristic features which are responsible for the success of steel reinforced concrete. Firstly, the coefficient of thermal expansion of concrete is very nearly identical to that of steel preventing internal stresses due to the differences in thermal expansion or contraction. Secondly, when concrete hardens its grip over the steel bar is very firm. This permits stress to be transmitted efficiently between both materials. Usually steel bars are roughened or corrugated to improve the bond further or to improve the cohesion between the concrete and steel. Thirdly, the alkaline chemical environment provided by Portland cement causes a passivating film to form on the surface of steel making it much more resistant to corrosion and making it neutral or acidic in conditions. Reinforced concrete ensures a structure of very great strength.
1.3 STRENGTH

Since the beginning of the use of concrete, strength has been regarded as one of its most significant and important properties. Strength of concrete is nothing but its resistance to failure. It may be measured in a number of ways, such as strength in compression, or in tension, or in shear or in flexure. Insufficient durability of concrete structures has become a serious problem. One of the most important parameters influencing the durability of concrete is its permeability. The permeability of concrete determines the ease with which gases, liquids and dissolved deleterious substances such as carbon dioxide or oxygen or chloride ions penetrate into the concrete. If the corrosion process has started, the rate of corrosion is still dependent on the supply of oxygen. The permeability of concrete is a major factor affecting the service life of reinforced components. Addition of waterproofing admixtures reduces the permeability of concrete and thus protects reinforcement from corrosion.

Concrete has been traditionally regarded as a durable material requiring a little or no maintenance. However experience shows that this is not the case, as many concrete structures are now showing signs of deterioration despite being only 20-30 years old. The major cause of deterioration is the chloride contamination of concrete and hence reinforcement corrosion.

1.3 ADMIXTURES

Admixtures are material added during mixing process of concrete in small quantities related to the mass of cement to modify the properties in the fresh and hardened state (Enyi et al 1994). They are now widely accepted as materials that contribute to the production of durable and cost effective concrete structures. The contributions include improving the handling properties of fresh concrete making placing and compaction easier, reducing
the permeability of hardening concrete and providing freezing and thawing resistance (Ramachandran 2001). Admixtures are frequently used to help in achieving the properties such as strength enhancement, density, resistance to water penetration, corrosion protection, finish enhancement etc. (Hewlett 1978). The effect of admixtures is dependent on the particular cement and additions of aggregate used in the concrete. Most admixtures are supplied as liquids as these are easily to dispense and disperse in the relatively small quantities used. The specified dose should be within the recommended range of dosage for the particular type and brand of admixture. The use of higher dosage results in reduced density and strength.

1.4.1 Types of Admixtures

Admixtures are classified into two types. They are:

1. Chemical admixtures and
2. Mineral admixtures

1.4.1.1 Chemical admixtures

Chemical admixtures are used to improve the quality of concrete during mixing, transporting, placement and curing. They fall into the following categories.

- Air entrainers
- Water reducers
- Set retarders
- Set accelerators
- Damp proofing and waterproofing admixtures
- Super plasticizers and
- Special admixtures which include corrosion inhibitors, shrinkage control, alkali-silica reactivity inhibitors and coloring.
Chemical admixtures are used to enhance the properties of concrete and mortar in the plastic and hardened state. These properties may be modified (IS 9103-1982).

- to increase compressive and flexural strength at all ages,
- decrease permeability and improve durability,
- inhibit corrosion,
- reduce shrinkage,
- accelerate or retard the initial set,
- increase slump and workability,
- improve pumppability and finishability,
- increase cement efficiency and
- improve the economy of the mixture.

Chemical admixtures are materials that are added to the constituents of a concrete mixture. They are added in most cases, specified volume in relation to the mass of the cement or total cementitious materials. Chemical admixtures reduce the cost of construction, modify properties of hardened concrete, ensure quality of concrete during mixing / transporting / placing / curing and overcome certain emergencies during concrete operations (Chong Yoon et al 1999).

1.4.1.2 Mineral Admixtures

Mineral admixtures make mixtures more economical, reduce permeability, increase strength and influence other concrete properties. They affect the nature of the hardened concrete through hydraulic or pozzolanic activity. Pozzolanas are cementitious materials and include natural pozzolans (such as the volcanic ash used in Roman concrete), fly ash and silica fume.
They can be used with Portland cement, or blended cement either individually or in combinations (Collepardi et al 1980).

1.5 WATERPROOFING ADMIXTURES

Waterproofing admixtures are one of the chemical admixtures. Waterproofing admixtures reduce water absorption of concrete and mortar without causing strength reduction further it reduces permeability etc. These waterproofing admixtures may be obtained in powder, paste or liquid form. In addition they also accelerate the setting time of concrete and thus render the concrete more impervious at early stage (Leber 1973). By reducing the volume of permeable voids within the concrete, these admixtures not only deliver a significant decrease in the permeability but also provide a positive waterproofing action (Mukesh Kumar 2009). It increases the concrete’s strength. Waterproofing admixtures can enhance the physical properties of concrete. For example, waterproofing admixtures provide increased compressive and flexural strength and increased chemical resistance. It is used to reduce material cost by reduction in cement without loss of strength or by increasing strength without additional cement. Waterproofing admixtures help to produce impermeable concrete for water retaining structures, terraces, basements, tunnels, pile foundations etc. Waterproofing admixtures can also provide significant cost savings because the application is so simple. Admixtures may be added either directly to the concrete at the batching plant, or to the ready-mix truck on the construction site (Ohama 1990). The need for labour-intensive application is eliminated. These waterproofing admixtures can be used for external and internal plastering of underground structures, tanks, masonry, screed, etc. Waterproofing admixtures may be of integral waterproofers or coatings.
1.5.1 Mechanisms of Actions of Superplasticisers

The rheology of cement paste is governed by Van der Waal’s attractive forces between cement particles and the electrostatic repulsion due to the surface charges on the cement particles. However, as the former force is larger than the latter, cement particles tend to eventually flocculate. The action of the superplasticiser is to prevent or delay the flocculation and to disperse the cement particles within the paste.

Flatt and Houst proposed that the behaviour of the superplasticiser (admixture) in the cement paste is made up of three components. The different interactions between the cement and superplasticizer which are often classified as physical or chemical interactions.

The first is the absorption of superplasticiser by intercalation (i.e., the incorporation of molecules of superplasticiser into the precipitates formed as the cement hydrates), co-precipitation (i.e., precipitation of tiny solid nuclei of the superplasticiser along with the precipitation of the cement hydrates) or micellisation (i.e., entrapment of groups of polymer molecules within the hydrating cement making them unavailable for active dispersion), leading to the formation of an organo-mineral phase. These phenomena that occur during the formation of erringite and C-S-H decrease the amount of admixture available for dispersing the flocs of cement later on. Consequently for the same superplasticiser dosage, a cement admixture combination with a high degree of absorption will yield less fluidity than another system with a lower degree of absorption. Nevertheless, the consumption of the superplasticiser by absorption is generally small, especially when the superplasticiser addition is delayed (i.e., the superplastiser is added at least few minutes after the addition of water to the cement.
The second part of the superplasticizer is adsorbed on the cement particles resulting in their dispersal due to the formation of an electrical double layer and consequent electrostatic repulsion between the particles. The chemical nature of the cement compounds that form the solid particle makes them undergo ionisation on the surfaces that are in contact with water. The organic superplasticiser molecules, having charged groups (SO$_3^-$, COO$^-$) interact with the particle surfaces imparting negative charges to the mineralogical phases of cement which results in mineralogical forces.

The third part of the superplasticiser is non-adsorbed species (Uchikawa et al 1992) may also be adsorbed subsequently maintaining the dispersion of cement particles leading to flow retention. The un-adsorbed molecules lead to additional mechanism of action of superplasticiser including the dispersion of cement particles by reducing the surface tension of the mixing water, the decrease in frictional resistance owing to the lining up of linear polymers along the direction of flow and the lubrication produced by the low molecular weight polymers between the particles (Gaidis and Gartner 1991).

Due to the dispersive action of the superplasticiser, water that would be otherwise entrapped within the flocs is released for providing fluidity to the paste. In other words the plasticizer reduces the amount of water needed for the effective dispersion of the cement particles. The electrostatic repulsion generated depends on the composition of the solution phase and the adsorbed amount of the superplasticiser (i.e., greater the adsorption, better the repulsion and higher the fluidity). As the electrostatic repulsion diminishes, flocculation of cement particles occurs and the cement paste eventually loses fluidity. This type of action is observed in the cases of melamine, ligno and naphthalene based admixtures (Yamada et al 2001).
Another type of physical interaction, also based on the adsorption that is observed in the case of polymer based type of admixtures. In addition to the electrostatic repulsive forces, is that the side chain polymer molecules cause steric hindrance between the cement particles, preventing flocculation and resulting in their dispersion. The steric repulsion depends on the length of main chain and the length and number of side chains. This action lasts for longer time than the electrostatic repulsion and hence leads to better performance (Singh et al 1992).

In addition to the physical effects of the adsorption, there are chemical reactions between the adsorbed superplasticiser and cement grains that occur mainly at most reactive sites of cement particle surface (Jolicoeur and Simard 1998). The sulphonate components reacts with C₃A in competition with SO₄²⁻ ions. Jolicoeur and Simard also pointed out that many organic admixtures solubilize the ionic species, through association or complexation, which delays the precipitation of the hydrated products. Also the presence of organic molecules in the solid solution inhibits crystal nucleation and causes slower growth of the hydration products and a change in their morphology (Ramachandran 1986). This is attributed to the blocking of the pores or gaps in the initial protective hydrate or the inhibition of the more reactive sites by the low molecular weight superplasticiser molecules.

The formation of air bubbles in the cement paste due to the incorporation of superplasticiser can also help in its fluidification but also could reduce the strength and durability if the air content is high. Different types of concrete differing influences on air entrainment in concrete, de-airing agents are sometimes added to the commercial product. Nevertheless, some of the air entrained due to the admixture incorporation is released when the concrete is vibrated, especially when it is highly workable (Mailvaganam 1999).
1.5.2 **Mode of Action of Waterproofing Admixtures**

Waterproofing admixtures may consist of pore filling or water repellent materials. The chief materials in the pore filling class are chemically active pore fillers (Nakajima et al 1992). These waterproofing admixtures fill the natural pores within the concrete or mortar to reduce porosity and improve water tightness. They increase the resistance of concrete to water penetration by creating a hydrophobic coating within the pores. The hydrophobic coating forces the water to be pushed out of the pore by surface tension (Rixom 1977).

Ordinary concrete even of high quality contains capillaries and micro cracks. This allows water to pass through its structure by an action similar to a tree drawing water to its canopy (Singh et al 1992). Concrete absorbs water because surface tension in capillary pores in the hydrated cement paste “pulls in” water by capillary suction. It is called capillary absorption. Figure 1.1 shows the “pull in” capillary suction and increase in contact angle (Lea 1970).

Integral waterproofing admixtures increase the resistance to capillary absorption. When they are mixed with concrete, it has two distinct waterproofing actions (Ramacahandran 1972).

The first waterproofing action is the reaction of hydrophobic components with concrete mix, which fundamentally changes its surface tension to produce a concrete, which is inherently water repellent and non absorptive throughout its entire mass. This means that an increase in the contact angle between the walls of the capillary pores and water, so that water is “pushed out” of the pores.
In the second action polymer globules moving with the bleed water during hydration gets collected in the capillaries when the hardened concrete is subjected to water pressure, these globules are compacted together to form a physical “plug” blocking the capillaries and thereby prevent water entry.

![Figure 1.1 Contact angle of water droplet with concrete surface](image)

For example, chemicals such as stearates (RCOOH) react with calcium hydroxide (Ca (OH)$_2$) and form insoluble calcium stearate (Ca$^+$COOR$^-$). It coats the capillary pores (Ma and Brown 1992).

$$\text{Ca (OH)}_2 + \text{RCOOH} \longrightarrow \text{Ca}^+\text{COOR}^- + \text{H}_2\text{O} \tag{1.1}$$

Theoretically, the effect of the high contact angle produced by the use of the waterproofing admixture means that 1 to 4 metre head of water would be required to penetrate the surface through the largest capillaries. The rain water has pressure head in centimeters. Hence penetration is almost impossible (Wanf and Gilliott 1992).

1.5.3 Corrosion Mechanism

The reinforcement steel in concrete is in highly alkaline environment due to the formation of calcium hydroxide, formed by the
hydration of cement. At this environment of higher alkalinity, reinforcement is protected by the passivate layer of ferric oxide, it does not initiate any corrosion. If the passivate layer is destroyed by any corrosion influencing factor, that the ferric oxide is reduced into ferrous oxide, it initiates corrosion (Uchikawa 1992).

Reinforcement steel is manufactured and exposed to the atmosphere where sufficient oxygen and moisture is available to react with steel. Oxidation of iron molecules naturally occurs. Corrosion of steel in concrete is an electrochemical process. When there is a difference in electrical potential along the steel reinforcement in concrete, electrochemical cell is setup. Steel becomes active or passive. In the steel one part becomes anode and other part becomes cathode. They connected by electrolyte in the form of pore water in the hardened cement paste (Yeomans 1975).

If the steel is active (more negative potential), the solid steel surface dissolves and goes into the solution as ferrous ions. This is called anodic reaction.

\[
\text{Fe (solid)} \rightarrow \text{Fe}^{2+} \text{ (ions)} + 2\text{e}^{-} \rightarrow \text{to cathode} \quad (1.2)
\]

Since the reaction releases electron, these electrons are simultaneously accepted in cathode, where oxygen reduction occurs. This is called cathodic reaction (Yamada 2001).

\[
\frac{1}{2} \text{O}_2 + \text{H}_2\text{O} + 2\text{e}^{-} \rightarrow 2\text{OH}^- \rightarrow \text{to anode} \quad (1.3)
\]

Thus one can see that oxygen (O\(_2\)) and water (H\(_2\)O) are required to the cathode reaction of the overall corrosion process. When concrete is dry oxygen is able to diffuse and reach the steel. When concrete is wet, water is able to reach the steel. Corrosion is usually accompanied by the formation of
solid corrosion debris from the reactions between anodic and cathodic products (Massazza 1981).

\[ \text{Fe}^{2+} + 2\text{OH}^- \rightarrow \text{Fe(OH)}_2 \text{ (Ferrous hydroxide)} \quad (1.4) \]

Pure Ferrous hydroxide is white but the material initially produced by corrosion is normally a greenish color due to partial oxidation in air.

\[ \text{H}_2\text{O} + \frac{1}{2}\text{O}_2 \rightarrow \text{Fe(OH)}_3 \text{ (Ferric hydroxide)} \quad (1.5) \]

Further hydration and oxidation reactions can occur with reddish rust.

1.5.4 Integral Waterproofers

Integral waterproofers are mainly used to reduce the water absorption and porosity or permeability of concrete and mortars. They also increase the cohesion of particles. It reduces the water demand for required workability and minimizes segregation and bleeding. These are broadly classified into three groups: permeability reducers, water repellents and polymer modifier. The major role of permeability reducers is to reduce the permeability of mortar or concrete. Such materials are specially used for marine structures (Young 1968). The chemicals in water repellents form thin hydrophobic layer within the network of cement mass by coating the cement particles. Polymer modifiers used are organic polymers, dispersed in water. These are now extensively used in the country these days as they impart better flexibility, reduce permeability, increase tensile strength and bonding behaviour of cement particles and hence provide excellent waterproofing properties (Colliepardi et al 1980).
1.6 NEEDSITY OF WATERPROOFING

The conventional technique of waterproofing are being used since the time, construction technologies for building are known to exist and have served the purpose to a great extent. In certain construction such as deeper basements, wider slab areas, high rise buildings facing rain and storms at high pressure, pre-cast elements etc., the use of wide variety of materials in such structures pose more challenging problems of waterproofing that ever before. Naturally the conventional techniques need to be supplemented by the new developments in this field. In this process the traditional methods of lime terracing mud-phushka with clay tiles, tar-felt or bituminous treatment etc are slowly giving way to various types of newly developed waterproofing materials or systems to check the ingress of water in buildings.

Waterproofing of concrete structures primarily roof slabs, terrace garden and basement has always been a challenging job for the contractors and Civil Engineers. Quality of concrete application and its subsequent waterproofing plays an important role in the durability of the structure. It has been often found that the seepage and leakage through concrete is a very common phenomena. Infact good concrete practice solves around 80 percent of the waterproofing problem. As the part of waterproofing process, major technological changes continue to occur with respect to the material, design and construction practices.

In recent years, various forms of waterproofing systems are available such as integral waterproofing compounds, building envelopes in the form of coatings, films and sheets sealants, injection grouting and polymer modified cementitious coating etc. These are being used for the prevention of leakage or seepage in buildings. A large number of commercial products based on these systems are available in the country, each claiming its merits.
The aim of waterproofing is to convert wettable capillaries to non-wettable types which would eventually lower the penetration of water into the system. The theory of capillary and the concept of capillary rise and capillary depression give basis for working of hydrophobic waterproofing materials.

The basic requirements for water-retaining structures are simply to have dense and durable concrete that has sufficient resistance against hydrostatic pressure without seepage of water through the concrete elements. Concrete normally contain voids. Cracks are also formed due to stresses under external loading conditions, internal thermal and shrinkage strains and structural movements etc.

To overcome the above deficiencies, measures have been developed mainly to reduce the cracks and voids so that passages for water are minimised. The cracks in concrete due to stresses induced by external forces have very little to do with concrete properties. The structural design should be done to control the stresses so that the crack widths are minimised. For cracks due to thermal and shrinkage effects, good design which limits the cement content and proper control when placing and curing the concrete are required.

1.7 OBJECTIVES OF THE STUDY

The objective of thesis is to study the effect of waterproofing admixtures on concrete properties and provide some guidelines for adopting appropriate concrete admixtures for waterproofing construction. Since waterproofing of concrete is a broad topic, this thesis only highlights the waterproofing admixtures to be included in watertight construction.

Dense and durable concrete can be achieved by sound mix design with a low water-cement ratio yet highly workable mix supplemented by
proper concrete placing and curing. However, there are always difficulties encountered on actual site, such as difficult access for concrete transportation, heavily reinforced sections etc. On the other hand, stringent requirements such as high strength concrete, low permeability and long durability for aggressive environment have to be fulfilled. To facilitate the construction work and fulfill the requirements of the specifications, there is a need to have the aid of waterproofing admixtures to produce such concrete.

Hence, the focus of the study is to characterize the mechanical and structural properties of concrete by the addition of waterproofing admixtures in terms of workability, strength and durability through various testing. Since the materials chosen in this research work are commercially available, the physical properties, the maximum and minimum dosage of admixtures to be used also given by the manufacturer itself. So the chosen admixtures are directly added with the conventional designed mix concrete and the change in properties are studied and discussed.

1.8 SCOPE OF THE WORK

One of the most important requirements of concrete is that it must be impervious to water under two conditions, firstly when subjected to pressure of water on one side, secondly, to the absorption of surface water by capillary action increasing the strength of the concrete. The concrete, carefully designed, efficiently executed with sound materials will be impermeable to water. However the usual design, placing, curing and in general the various operations involved at the site of work leaves much to be desired.

The intention of the project is to study the effect of addition of waterproofing admixtures on the increase on compressive strength, tensile strength, flexural strength, workability, durability (corrosion test) and
reduction of the permeability of concrete. It is proposed to conduct the following tests with and without the addition of admixtures of different dosages and various curing periods.

1. **Workability Test:** To study the effect of waterproofing admixtures on the workability of concrete with various waterproofing admixtures and different w/c ratios such as 0.55, 0.60 and 0.70 are studied by using slump cone apparatus.

2. **Mechanical strength Tests:** To study the effect of waterproofing admixtures in the mechanical properties of concrete, mechanical strength tests using the standard test specimens were carried out. The properties such as compressive strength, split tensile strength, modulus of rupture and modulus of elasticity were obtained. There are five different admixtures used with three different dosages (dosage is taken as specified by the manufacturer of the admixture) and tested after the curing periods of 7 days and 28 days. The test results were compared with conventional concrete and discussed in this thesis.

3. **Permeability Test:** The important objective of this thesis is to find the permeability property of concrete using waterproofing admixtures. For this study, different waterproofing admixtures were mixed one by one with concrete, each of three different dosages, cast and cured for 7 days and 28 days. The tests were carried out using standard permeability apparatus as per IS 2645:2003.

4. **Corrosion Test:** To find out the corrosion behaviour of reinforced concrete, it is proposed to conduct accelerated
corrosion test. To accelerate the reinforcement corrosion, direct electric current was impressed on the rebar embedded in the specimen using a DC power supply system for 100 hours. The current was monitored and recorded at regular intervals. The expected amount of corrosion in terms of mass loss of the reinforcing bar due to corrosion by the addition of admixtures measured and discussed in this thesis.

5. **Chemical resistance Test:** To study the effect of chemical resistance of concrete due to the addition of waterproofing admixtures, acid and alkaline test have been carried out. For acid resistance test, the specimens were cured for 28 days and immersed in 1% by weight of sodium chloride for 90 days and for alkaline resistance test, the specimens were cured for 28 days and immersed in 1% by weight of sulphuric acid for 90 days and the effects on loss of weight in the specimens with and without admixtures are compared and discussed.

Rapid chloride penetration test (RCPT) was also carried out as per ASTM C 1202 to determine the electrical conductance of the concrete with and without admixtures at the age of 28 days curing and to provide a rapid indication of its resistance to the penetration of chloride ions. The test method consists of monitoring the amount of electrical current passed through 51 mm thick and 102 mm nominal diameter of cylindrical specimens for the duration of six hours. The total charge passed during this period was calculated in terms of Coulombs.

6. **Drying Shrinkage Test:** The effect of addition of waterproofing admixtures on the drying shrinkage property of concrete is studied by using standard prism specimens as per
ASTM C 157/C. The specimen was fixed in the appropriate place of the apparatus and the readings have been taken from the dial gauge mounted on it. The drying shrinkage values have been obtained for the specimens for the periods of 28 days, 60 days and 90 days are compared with the conventional concrete and the results were discussed.

1.9 ORGANISATION OF THE THESIS

The thesis consists of five chapters, Introduction, Literature review, Experimental investigation, Results and discussion and Summary and Conclusions. Chapter 2 presents a review of literature regarding waterproofing admixtures and their properties. Chapter 3 presents the experimental methodology which deals about the materials used and different testing procedures. The results obtained from experimental investigation are presented, critically discussed and compared in Chapter 4. Chapter 5 presents the summary and conclusions.