BE CIVIL ENGINEERING PROJECT REPORT

PERMEABILITY ASSESSMENT OF CONCRETE WITH ADMIXTURES AND BACTERIAL MINERALIZATION

Project submitted in partial fulfillment ofthe requirements for the degree of

BECivil Engineering

SUBMITTED BY

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MILITARY COLLEGE OF ENGINEERING

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This to certify that the

BE Civil Engineering Project entitled

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Has been accepted towards the partial fulfilmentof therequirements for

BE Civil Engineering Degree

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Dr. Sarfraz Ahmed, Ph D
Syndicate Advisor

Dedication

Special dedication to my parents
My supervisor, my beloved friends,

and all faculty members

For all support, encouragement and believe in me. Thank you so much.

ACKNOWLEDGEMENT

Countless gratitude to Almighty, Allah, who is Alpha and Omega and He is the master of pen and the board. He provided us the opportunity, time, health, and ability to complete the task assigned. And with His grace we stand before this panel to be judged righteously

We are very thankful to our affectionate and great parents because their love and prayers enabled us to achieve this goal.

Never the less praise be upon our instructors of MCE who enabled us through their superb coaching to pass all the courses prescribed for achieving Civil Engineering degree. We are especially indebted to our highly regarded instructor and advisor Lt Col Dr. Sarfraz Ahmed who gave us support and right direction to complete our project.

Special thanks are reserved for Sika Chemicals and all others who provided us valuable assistance in the compilation of the project.

All Syndicate members

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LIST OF ABBREVIATIONS/SYMBOLS

ASTM	American Society for Testing and Materials
AS	Australian Standards
CCAA	Cement Concrete and Aggregate Australia
Fig	Figure
Ksi	Kips per square inch
LWA	Light Weight Aggregate
MPa	Mega Pascal
OPC	Ordinary Portland Cement
Psi	Pounds per square inch
PCC	Plain Cement Concrete
UTS	Universal Testing Machine
W/C	Water Cement Ratio

EXECUTIVE SUMMARY

It is a well-known fact that concrete structures are very susceptible to cracking which allows chemicals and water to enter and degrade the concrete, reducing the performance of the structure and also requires expensive maintenance and repairs. Cracking in the surface layer of concrete mainly reduces its durability, since cracks are responsible for the transport of liquids and gasses that could potentially contain deleterious substances. Water in many ways can make a building weaker structurally thus permeable concrete results in reduced service life of the structure. Spalling of paint due to water seepage increases the maintenance cost of the structure. Water seepage results in damp and unhygienic interior which promotes the growth of microorganisms.

One of the most important deficiency which needs to be reduced is the *Permeability of concrete*. There are various techniques, used for assessing the permeability issue. The main aim of our project is to evaluate various techniques, such asuseof admixtures, plasticizers, crystalline waterproofing and bio-mineralization of bacteria in concreteto reduce its permeability.The study results reveal that combination of the two used admixtures (Sika-1 &Sikament 512PK) was most effective technique in reducing permeability of the concrete by 30%. The overall effectiveness of Sika-1, Sikament 512 PK, gypsum and surface applied crystalline water proofing chemical were found 19%, 21%, 3% and 12% compared to the non-treated/ control concrete respectively.

Use of admixtures in the concrete along with good workmanship resulted in significant decrease in permeability.

Keywords: Permeability, Aggregate gradation, Strength, Admixtures, Bio-mineralization

CHAPTER 1
INTRODUCTION

1.1 Background

It has always been the effort of mankind to make its surroundings as pleasant and comfortable as possible. Whether he was a caveman or a modern 21st century protégé we find that he has always been making the maximum effort to do so. To save himself from the elements of nature he resorted to construction of various dwellings for himself. In the beginning it was the caves but as humanity progressed so did the standard of his living also improve. He started making stone houses for himself, progressing to brick masonry structures and ultimately to stately mansions of the present day society which we find scattered all over the world today.

However whether it was the caveman working to improve his cave or it was a modern age builder, nature has always been a challenge for them. Especially the problem of water proofing remains as much as today as it was present ages ago. We find our predecessors in the same dilemma in which we find ourselves today that is to conquer these elements of nature to suit our own needs.

The key to successful water proofing is how to make concrete itself permeable, since the body of the concrete provides the ultimate barrier to water travel even if the water proofing applications fail. There is no concept of fixed quantity of water addition in mix at sites. Although slump test is one method to restrict excessive use of water but that too is not normally practiced due to lack testing facility or awareness of workers. The workers in order to reduce compacting effort required have the tendency to add excessive water to the mix unmindful of the harm it can do to the concrete. The excessive water added, when evaporates leaves the concrete with excessive interconnected capillary pores, which provide path for water to seep. Based on the microscopic level study numerous measures can be taken to make concrete its self-watertight.

Carbon dioxide and sulphur dioxide from the atmosphere reduce this alkalinity by carbonating the alkalis, and increase the vulnerability of the steer to corrosion and rusting. Inadequate cover and poor concrete exacerbate the carbon anion problem. The result is cracking as the rusting steel expands followed by spalling of concrete cover. Rust staining is also often present. Sulphate attack can occur to a concrete in contact with sulphate-contaminated ground. Sulphate resisting Portland cement must be used instead of ordinary Portland cement below or at ground level. Concrete is also vulnerable to chloride attack. In marine atmospheres, even no reinforced has been known to disintegrate if heavily attacked by sea salts. However, chloride attack has also occurred through the use of calcium chloride admixtures, or the presence of chlorides in aggregate.

The durability of the building material is massive subject which this one chapter cannot hope to cover exhaustively. Concrete is widely used construction material but still it has its own complexities and it has to used according to its requirements. According ot is a very strong material but in actual it is very sensitive to physical and chemical agents. The construction material of a building may become responsible for hinderers of defects later on, if not used properly.

A material failure of building component is usually due to one of following three factors:

1. An inherent weakness in the material due to fault in its manufacture.
2. Poor design, where the material has been used in situation for which it is not suited.
3. The degradation of materials through the attack of an agent.

Our research study follows the same course, finding ways of making concrete a waterproof material. Mainly every failure of concrete end up making path for the water to flow through it causing water leakage either it is cracking or poor workmanship. Later in this research thesis are discussed some techniques serving the purpose.

1.2 Problem Statement

Concrete is the most commonly used man made construction material. It has become very popular not only among civil engineers but among common people also. The secret of its popularity lies in the simple fact that except cement, all other ingredients of concrete are commonly available local materials like aggregate and water. Therefore it is no surprise that the concrete is being used as a construction material from small pavements to run-ways, from small hutments to multi-story buildings and from small culverts to long multi-span bridges. Unfortunately concrete is a porous product, any concrete that is exposed will be subject to penetration by liquids and gases when subjected to wetting and drying. The take up of water and resultant expansion being a factor vary according to the mix design and quality control on site. This wetting is always more pronounced on the most exposed areas. Many of the problems of concrete durability occur because of this water penetration. Probably the simplest defect is that of frost action on saturated material. Susceptibility to attack is usually related to poor quality of concrete.

Impermeability of concrete, apart from its direct bearing on water tightness, is also important for its influence on durability. Concrete is not the only material vulnerable to physical and chemical processes of deterioration associated with water. Water is the primary agent of both creation and destruction of many natural materials. It happens to be central to most durability problems in concrete. The wetting of the concrete can also cause reactions with other constituents of the mix, or between the concrete and an outside agent, the corrosion of reinforcement probably being the commonest. With water tightness the concrete can be made to resist corrosion of steel, freeze thaw, sulphate attack, alkali aggregate reaction, carbonation, efflorescence etc.

More than 95% of the building roof slabs in our country are made with conventional 1:2:4 mix concrete, in which there is no concept of using a measured quantity of water. Waterproofing in many cases is only restricted to using bitumen and that too of low quality on the roof tops.

Poor structural design with inadequate provision for creep deformations make the roof slabs deflected downward letting rain water to pond and will ultimately seep through. The shrinkage cracks which will develop with the passage of time during the life span of the buildings will further add to the leakage problem.

There are various methods and materials in use, for waterproofing in our country. But most of them fail due to one or another reason. A successful waterproofing depends upon quality and durability of the waterproofing materials, and the quality and design of the structure itself.

1.3 Objective of the Study

The objectives of study were:

- To compare the effectiveness of different techniques to reduce the permeability of concrete.
- To design a suitable concrete mix (1:2:4) with admixtures/waterproofing agents meeting strength requirements.

1.4 Scope and Limitations of the Study

In order to archive the above mention objectives:

- To devise best possible combination of techniques in order to reduce the permeability by making different test samples under the laboratory, using locally available admixtures.
- Appropriate amount of super plasticizers will be used to achieve maximum water reduction, to produce a consistent mix with minimum voids having the desirable properties.
- To suggest most feasible combination of techniques that would be used without disturbing the desired properties i-e workability, consolidation, durability etc.
- Since waterproofing concrete is a broad topic, this thesis only highlights the admixtures to be included in concrete for watertight construction. These structures include roof structures, basements etc. Waterproofing materials such as membrane and sheets are not dealt with in this report.
- Attempt will be made to incorporate dormant but viable bacteria in the concrete matrix which will contribute to the strength and durability of the concrete. Self-repairing concrete biologically produces calcium carbonate crystals to seal cracks that appear on the surface of the concrete structures.
- As biological engineered concrete is relatively a new technique and procurement of bacteria is a timely process so further study of bacterial concrete is not included in this research thesis. However specific bacteria and bacterial food for incorporation in concrete is identified in this thesis.

1.5 Organization of the Report

The thesis is ordered in six chapters; brief description of each is as follows:

- **Chapter 1: Research background**. It describes the research need and purpose, its objectives along with scope and limitations.
- **Chapter 2: Literature review**. It covers the detailed literature review part of the thesis which will include recent techniques and methods which are followed in past studies.

- **Chapter 3: Research methodology**. It describes the overall research strategy, the research design, laboratory test procedures and methods for analysis of obtained data
- **Chapter 4: Laboratory Testing, Data Analysis and Results.** It covers analysis of data and detailed discussion of the results. Which include ranking of permeability reducing techniques, both for fresh and hardened concrete.
- **Chapter 5**: **Bio-Mineralization of Bacteria in Concrete.** It covers the advance permeability reducing technique which includes incorporation of specific bacteria in concrete during casting.
- **Chapter 6: Field Application.** On the basis of laboratory testing, permeability reducing techniques are employed in field. Both existing and new structures are treated with waterproofing chemicals to test their effectiveness under field conditions.
- **Chapter 7: Conclusions and Recommendations**. The problem of leakage/ seepage is very complex and therefore its solution is not easy and straight forward. Approach to the problem will be multidirectional which must include treatment / improvement in design and construction of the structural elements and the building as a whole. The conclusions and recommendations reached to through our study and experimental work are statedin this chapter.

1.6 Summary

This chapter provides the background and need for the conduct of this particular study i-e Permeability of Concrete. Problem statement shows the elaborated problem which we intend to address. The objectives which we have kept in mind during this research are briefly described. As we know that no study is complete as a whole, so this brought up a need to elaborate our scopes and limitations of study. Furthermore, this chapter offered overview of this dissertation.

CHAPTER 2
LITRATURE REVIEW

2.1 Introduction

Any construction activity requires several materials such as concrete, steel, brick, stone, glass, clay, mud, wood, and so on. However, the cement concrete remains the main construction material used in construction industries. In recent years, durability of concrete structures have become the cause of concern to all. Strength of hardened concrete is its most important property. However, for aggressive exposure conditions, durability, volume stability, and impermeability are equally important. The general assumption is that an improvement in concrete strength will improve its other properties as well, except many important exceptions, for example, an increase in cement content that may be intended to increase the strength may also increase the amounts of shrinkage and creep.

Since concrete is a brittle material, its porosity primarily governs its strength. The strength is found to be severely decreasing with increase in the porosity. The porosity of concrete which governs the strength of concrete is affected by the spaces or pores in concrete. "The pores ratio is the space available for the hydration products" (Neville A.M 1987). Low number of pores results in increase in the strength of concrete. The process which governs the porosity of concrete affecting its strength, is affected by the water/cement ratio of concrete. A higher w/c ratio lead to increasing of the porosity thereby decreasing the strength of concrete. The ultimate strength of concrete is influenced by the w/c ratio, the design constituents, and the mixing, placement and curing methods employed. All things being equal, concrete with a lower w/c ratio makes a stronger concrete than that with a higher ratio. The total quantity of cementations materials (like pozzolans) can affect strength, water demand, shrinkage, abrasion resistance and density. All concrete will crack independent of whether or not it has sufficient compressive strength. In fact, high Portland cement content mixtures can actually crack more readily due to increased hydration rate. As concrete transforms from its plastic state, hydrating to a solid, the material undergoes shrinkage. Plastic shrinkage cracks can occur soon after placement but if the evaporation rate is high they often can actually occur during finishing operations, for example in hot weather or a breezy day.

2.2 Concrete Durability

Concrete is well known load bearing material. It seemed to be cardinal property so much so that the recommendation in selection of concrete are made basing upon its strength. But with the time it has been realized that the concrete is not an inert material immune to the environmental conditions to which it is exposed.Durability of concrete is its ability to resist weathering action, chemical attack, abrasion, or any process of deterioration. There are chemical and physical interactions which has significant effect on the durability and hence on the service life of the concrete. Many structures deteriorated much before the stipulated time causing a lot of economic damage and public inconvenience. Durability is thus attracting more and more world attention and is becoming more and more important. In the ancient times the durability problems were no reported so much as they are today. “It may be that the concrete in the past had much denser structure thereby it was more impervious to water and gasses” (Faulkner H. F. 2000). Besides, today the environment is much more aggressive than was in the old times, concrete faces more environmental abuse. In the ancient times, more attention was given to the quality of concrete. Proper supervision of the concrete-making process was of prime importance and the raw materials used were very carefully selected. “It is tempting to ask why after all these years of research, there are still many problems with the durability of concrete may. Probably there are more problems these days than fifty years ago”. (Neville A. M. 1987).

As we can see that strength and durability are key properties of concrete. They are “should” properties of concrete without them there is no use of the product. Now the question arises; what is the reason for the absence of these properties from concrete? The answer lies in the heading of the research paper: Permeability of Concrete. Permeability has devastating effect on the strength of concrete. Water permeable concrete will slowly damage and hence will be liable to failure at any time. Permeability of concrete plays an important role in durability because it controls the rate of entry of moisture that may contain aggressive chemicals and the movement of water during heating or freezing. Higher the permeability lesser will be the durability.

Further in this chapter is discussed concrete permeability, factors affecting permeability and measures in practice to reduce permeability of concrete.

2.3 Concrete Permeability

Permeability is the process of transmittance of fluids through the material due to its porosity caused by different reasons. Long-term performance of concrete structures is associated with both concrete strength and durability properties, e.g., Permeability which is a governing property to estimate durability of a concrete structure i-e durability is directly proportional to permeability. So if concrete is more permeable then durability will get lesser over the time. In terms of deterioration of concrete due to physical or chemical causes, the mobility of fluids through the concrete are nearly always involved. "The overall penetrability of a concrete structure, especially when compounded by additional environmental or exposure challenges, is the key to its ultimate strength and durability". (Grunsky 2005). Low porosity or permeability of concrete to moisture and gas is the first line of defense against: frost damage, acid attack, sulfate attack, corrosion of steel embedment and reinforcements, carbonation, alkali-aggregate reaction, and efflorescence.

Generally some properties of concrete that make it less permeable also make it more watertight. Decreased permeability improves concrete's resistance to desaturation, sulfate and other chemical attack, and chloride ion penetration. Permeability also affects the destructiveness of saturated freezing. A low permeability concrete requires a low w/c ratio and adequate moist- curing. Permeability increases with drying.

2.3.1 Concrete Permeability as Degradation

Permeability is an important property with regard to the durability of concrete. (Young 1988). Permeability deteriorates the concrete in following ways:

i. Water is responsible for corrosion of embedded steel in the concrete. The steel after rusting increases in volume and thus the concrete cover spalls, which leaves the structure more to prone to environmental effects.

ii. Due to seepage of water through concrete the paint on the inner side of the structure peels off and will require regular maintenance, and thus will increase maintenance cost of the structure.
iii. As a solvent, water is noted for its ability to dissolve more substances than any other known liquid. This property accounts for the presence of many ions and gases in some waters, and thus water act as a vehicle for transport of aggressive ions, becoming the instrumental source of chemical possesses of degradation and decomposition of concrete. Deleterious chemical effects include leaching of the cement paste by acidic solutions, and expensive reaction involving sulfate attack, alkali-aggregate reaction.
iv. Water has the highest heat of vaporization among the common liquids; therefore, at ordinary temperatures it has a tendency to exist in liquid state in porous material, rather vaporizing and leaving the material dry. Furthermore, with porous solids, internal moisture movements and structural transformations of water are known to cause disruptive volume changes of many types. For example, freezing of water into ice, formation of an ordered structure of water inside the fine pores, development of osmotic pressure buildup by differential vapor pressures can lead to high internal stresses, leading to cracks.
v. Once its alkalinity has been reduced by carbonation, a concrete surface will provide suitable conditions for biological colonization. They require moisture and some traces of mineral salts for survival. The first colonizers of a surface are micro-organisms: algae, fungi and associated bacteria; visible growths of algae or lichens appear. Dirt sometime collects on colonizes surface and this, together with dead lichen, can provide a footing for mosses and later even for more developed plants.

2.4 Factors governing Permeability of Concrete

For a subject which is of vital importance for every structure, factors which govern the water permeability of concrete has received surprisingly little consideration, at least from concerted research standpoint. The importance of water permeability of concrete has long been realized and statements by engineers have appeared which attributes many failure and unsatisfactory conditions to this factor (Renz1999). Some factors are:

2.4.1 Influence of aggregate

The aggregate itself are very less permeable and do not affect permeability directly, however, the properties of aggregate not only affect the certain properties of fresh concrete but also affect the durability and time dependent performance of hardened concrete. Aggregate initially was viewed as an inert material dispersed throughout the cement paste largely for economic reasons. Mindess (1981) states that to design workable concrete, of adequate strength and durability, a range of properties of coarse aggregate must be known, such as shape and texture, grading, moisture content, specific gravity and bulk density. In modern view aggregate is a building material connected into cohesive whole by means of cement paste, and aggregate is not truly inert and sometimes its chemical properties influence the performance of aggregate; it gives considerable technical advantage in concrete like higher volume stability in concrete and better stability in concrete and better durability than cement paste alone. The direct or indirect effect of properties of aggregate on permeability and durability of concrete are discussed below

i. **Particle shape.** The external characteristics of aggregate are of importance particularly particle shape and texture. One of the aspects of the shape of coarse aggregate is its sphericity, defined as the function of the ratio of surface area of the particle to its volume. Sphericity is related to bedding and cleavage of parent rock and is also influenced by type of crushing equipment when the particle are artificially reduced. Particles with higher ratio of surface area to volume (elongated and flakey particles) tend to increase the permeability indirectly as they reduce workability and increase the water demand for the same weight of aggregate because more surfaces are to be wetted. Such particles also affect adversely the durability of concrete as they tend to orient in one plain, with water and air voids forming underneath.

ii. **Surface texture.** The interface of aggregate and cement matrix is very critical and if not properly bonded is preferable path for the seeping water. The bond between the aggregate and the cement matrix, other than the mineralogical and chemical composition of aggregate, depends on the surface texture of aggregate. A rougher texture result in a greater adhesive force between particles and cement matrix. A porous aggregate will result in better bond than the texture characteristics which permits no penetration.

2.4.2 Shrinkage effect

Concrete is subjected to changes in volume either autogenously or induced. Volume change is one of the most detrimental properties of concrete, which affects the long-term strength and durability. To the practical engineer, the aspect of volume change in concrete is important from the point of view that it causes unsightly cracks in concrete. One of the most objectionable defects in concrete is the presence of cracks. One of the important factors that contribute to the cracks is that the shrinkage. It is difficult to make concrete which does not shrink and crack. It is only a question of magnitude (Banta 1996). Concrete shrinkage may occur throughout a structure's life cycle for different reasons with the majority occurring within the first few months or years after casting. There are two primary categories of shrinkage: plastic shrinkage in initial stage, and dry shrinkage in hardened state (Barr et al 2006). Immediately after concrete is poured, there can be settlement shrinkage, construction movement e.g. formwork movement or removal. After the concrete has fully hardened, a structure will undergo temperature, volume and chemical changes throughout the years leading to hardened cracking. Each of these may also cause concrete shrinkage.

Tareq Salih Al-Attar (2008) in his paper on "Effect of Coarse Aggregate Characteristics on Drying Shrinkage of Concrete" said that Concrete is a composite material, consisting, mainly, of three phases: coarse aggregate, cement mortar and the interface zone between them. The characteristics of the interface zone largely govern the bond between cement paste or mortar and aggregate. The restraining effect of aggregate to drying shrinkage strain depends much on the bond between aggregate and cement paste. It is concluded that using saturated coarse aggregate always yields higher shrinkage strain than dry aggregate. The percentage increase seems to be affected by the aggregate water absorption at the early ages. After 28 days, there are large differences in relative shrinkage for different mixes. Later than 28 days, the variation in ratios settled to approximately fixed values.

i. **Plastic Cracks.** Plastic crack form in the initial stage of the setting of concrete when the water during curing dry of very quickly or settlement during setting. These are hairline cracks just on the surface of the concrete paving the way for the moisture to enter n cause severe cracking. The thin lines may be misleading; although they may be very thin, these hairline cracks may extend through the entire thickness of the slab.

ii. **Hardened Cracks.** Hardened cracks occur after the concrete has hardened, and are generally caused by drying shrinkage, settlement of the structure below grade, and thermal contraction effects. The cracks form because while the concrete is drying, its volume is being reduced. Drying shrinkage is the shrinking (or reduction in volume) of the concrete due to loss of water (evaporation through the concrete surface).

2.4.3 Shrinkage issue as a permeability

Shrinkage manifests itself soon after the concrete is placed in the forms while the concrete is still in the plastic state. The loss of water results in the reduction of volume. The aggregate particles or the reinforcement comes in the way of subsidence due to which cracks may appear at the surface or internally around the aggregate or reinforcement. Any type of cracks caused by shrinkage will ultimately result in making concrete permeable. As discussed shrinkage cause cracks on the surface as well as inside the concrete along the aggregate. These cracks are the clear passage for water to travel into the concrete making it suitable candidate to failure. Water entering through shrinkage cracks slowly seeps down. This slow movement of water is dangerous for concrete. The path followed by water inside concrete, on that path it weakens the concrete leaving it porous like sponge. Thus any loading or even under existing loading concrete is sure to make a fall.

2.5 W/C ratio effecting permeability

Porosity cement paste govern the concrete permeability. Since porosity of a cement paste depends on the w/c ratio and the age of the cement paste, these factors affect the paste permeability and therefore the concrete permeability. For a given w/c ratio, the permeability decreases with age as the cement continues to hydrate and fills some of the original water space, the reduction in permeability being faster at the lower w/c ratio. Besides porosity of the paste, segmentation of capillary pores is another major factor, which affects the permeability. For the same porosity of a paste, the permeability will be lesser in case of capillary pores being segmented disrupting the continuity of pores, as compared to the case of interconnected capillary pores. A mix with a low w/c ratio is advantageous because the stage at which the capillaries become segmented is achieved after a shorter period of curing.Water is necessary to make concrete. But it is a media in the deterioration of concrete. For example, calcium hydroxide is dissolves in water, which leaches out, thereby the strength of concrete is decreased. Freeze-thaw damage to the concrete occurs when the concrete is saturated with water. Water can dissolve many salts and can make acid droplets by dissolving gases from the atmosphere, which then penetrate into concrete and become particularly instrumental in causing its chemical deterioration.

2.6 Permeability reduction measures in practice

2.6.1 Addition of Pozzolonas

2.6.1.1 Background

A pozzolana is a natural or artificial material containing silica in a reactive form. By themselves, pozzolanas have little or no cementitious value, but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide liberated on hydration, at ordinary temperature, to form compounds possessing cementitious properties.

The technical advantage of using pozzolana cements and slag cements is derived mainly from three features of the pozzolanic reaction.

1. The reaction is slow; therefore, the rates of heat liberation and strength development will be accordingly slow.

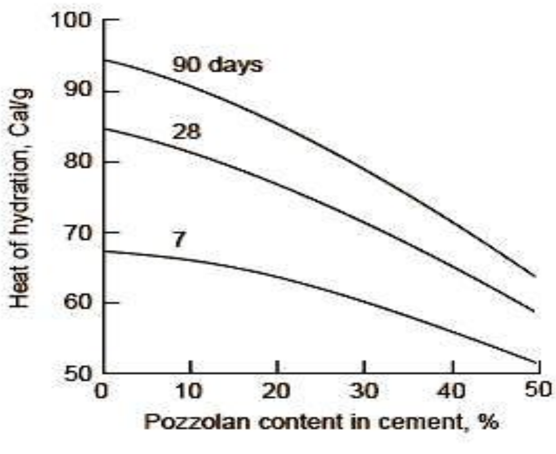


Figure 2.1: Change in heat of hydration due to variation in pozzolanic content in cement (Mehta, P.K, (2006). "Concrete microstructure, properties and materials". Pg 232. The Mcgraw hill companies, U.S.A.)

2. The reaction is lime-consuming instead of lime producing, which has an important bearing on the durability of the hydrated paste in acidic environments.
3. Pore size distribution studies have shown that the reaction products are very efficient in filling up capillary spaces, thus improving the strength and impermeability of the system.

2.6.1.2 Pozzolonic Reaction

On hydration tri-calcium silicate and di-calcium silicate, calcium hydroxide is formed as one of the products of hydration. This compound has no cementitious value and may be leeched out by the percolating water. The siliceous and aluminous compound in a finely divided form, reacts with calcium hydroxide by the pozzolanic reaction to form highly stable cementitious material of fine pore structure, Pozzolanas must be finely divided in order to expose a large surface area to the alkali solutions for the reaction to proceed. The silica in a pozzolana has to be amorphous, or glassy, to be reactive.

$$\text{Pozzolana + Calcium Hydroxide + Water} \longrightarrow \text{C – S – H (Gel)}$$

This reaction is called pozzolanic reaction. The characteristic feature of pozzolanic reaction is firstly slow, with the result that heat of hydration and strength development will be accordingly slow. The reaction involves consumption of Ca $(OH)_2$ and not production of $Ca(OH)_2$. The reduction of $Ca(OH)_2$improves the durability of cement paste by making the cement paste dense and impervious.

The pozzolanic materials can be classified in to two groups

a. Natural Pozzolanas

i. Clay and Shales.
ii. OpalincCherts.
iii. Diatomaceous Earth.
iv. Volcanic Tuffs and Pumicites.

b. Artificial Pozzolanas

i. Fly ash.
ii. Blast Furnace Slag.
iii. Silica Fume.
iv. Rice Husk ash.
v. Metakaoline.

vi. Surkhi.

2.6.2 Water-Proofing Agents

Waterproofing admixtures reduce capillary absorption of water into hardened concrete as well as reduce the passage of water through concrete under pressure head. Most water reducing admixtures function in one or more of the following ways:

a. Reduce the size, number and continuity of capillary pore structure.
b. Blocking the capillary pore structure.
c. Lining the capillaries with a hydrophobic material to prevent water being drawn in by absorption/capillary suction.

All these ‘waterproofing’ admixtures reduce surface absorption and water permeability of the concrete by acting on the capillary structure of the cement paste. They will not significantly reduce water penetrating through cracks or through poorly compacted concrete which are two of the more common reasons for water leakage through concrete.

2.6.2.1 Mechanism

Waterproofing agent works on pore-blocking mechanism, which is based on very fine reactive or unreactive fillers or insoluble polymer emulsions, which have particle size of around 0.1 microns and are small enough to get into the capillaries during the early stages of hydration and physically block them.

The hydrophobic admixtures are usually designed to be soluble as an admixture but react with the calcium of the fresh cement to form an insoluble material which adsorbs onto the surfaces of the capillaries. Once the capillary dries out, the hydrophobic layer prevents water re-entering the capillary. One of the waterproofing agent is discussed below.

2.6.2.2 Platocrete N

Plastocrete-N is a concrete admixture in liquid form that acts both as a highly efficient plasticizer and waterproofing agent. It is suitable for use in tropical and hot climatic conditions. It can be used in structural as well as mass concrete, particularly water retaining structures.Plastocrete-N complies with ASTM C 494 Type A.

2.6.2.2.1 Advantages

Plastocrete-Nprovides the following properties:

a. Improved workability without increased water content.

b. Allows easier compaction leading to denser concrete and superior finish.

c. Increased strength and durability.

d. Reduced shrinkage.

e. Improved water tightness.

2.6.2.3 Overviewof Platocrete N:

Table 2.1Overview of properties of Platocrete N

Property	Detail
Dosage	0.5% by weight of cement
Dispensing	Plastocrete-N should be dispensed into the mixing water prior to its addition to the aggregate
Concrete Placing	Standard rules of good concreting practice must be observed
Curing	Fresh concrete must be cured properly specially at high temperatures in order to prevent plastic and drying shrinkage
Compatibility	Plastocrete-N can be combined with Sikapump, Sika-Aer and Sikament admixtures. It is also compatible with sulphate resistant cement
Cleaning	Clean all equipment and tools with water immediately after use
Remarks	When accidental overdosing occurs, apart from retarding the initial set no detrimental effect will take place. During this period the concrete must be kept moist in order to prevent premature drying out

2.6.3 Water Reducing Admixtures/Workability Aid

Materials that increase the fluidity of the cement paste without significantly affecting the air content and thereby increasing the workability of the concrete at constant water/cement ratio, or permits concrete to be made with a decreased amount of water while maintaining equal workability, with a consequent increase in strength are called water reducing admixtures.

To reduce compacting efforts, high workability is required in field. The recommended methods for obtaining high workability is by improving the gradation of coarse aggregate, use of relatively higher percentage of fine aggregate or by increasing the cement content and with optimum quantity of water. Since it is difficult to obtain well graded aggregate and an increase in cement content leads to an increase in material cost, heat of hydration and shrinkage, therefore the easy method generally followed at the site is to use extra water to fluidize the concrete unmindful of the harm it can do to the strength and durability of concrete. It is an abuse and totally non engineering practice.

Since the permeability of the cementitious matrix plays a fundamental role in the deterioration process, the water cement ratio is the crucial parameter to be controlled. To reduce the water cement ratio, either the cement content has to be increased or the water content has to be decreased. Also, reducing the water content to decrease the water cement ratio will cause the reduction of the workability of the concrete mix. The stiffer is the concrete mix the more compacting effort it will require to achieve full compaction. This will require powerful compaction equipment and longer placing times, and if this is not done properly the hardened concrete will result in to be more porous. Therefore water reducing admixtures are used.

Therefore, the role of water reducing admixtures having secondary functions, such as long slump retention, are of extreme importance for reducing the water cement ratio and hence as a consequence, the porosity and permeability of the hardened concrete. All durability factors relating to the porosity and permeability such as chloride diffusion, sulphate ingress, rate of carbonation, etc. are therefore improved.

2.6.3.1 Mechanism

Portland cement, being in fine state of division, will have a tendency to flocculate in wet concrete. These flocculation entraps certain amount of water used in the mix and thereby all the water is not freely available to fluidity the mix. When water reducing admixtures are used they get adsorbed on the cement particles. The adsorption of charged polymers on the particles of cement creates particle to particle repulsive forces which overcome the attractive forces. This repulsive force is called Zeta potential, which depends on the base, solid content and quantity of admixture used. The overall result is that the cement particles are deflocculated and dispersed.

When cement particles are deflocculated the water trapped inside the flocs gets released and become available to fluidity the mix.

When cement particles get flocculated there will be inter particles friction between particle to particle and floc to floc. But in the dispersed condition there is water in between the cement particles and hence the inter particle friction is reduced. One of the water reducing admixture is discussed below:

2.6.3.2 Sikament-NN

Sikament-NN is highly effective dual action liquid superplasticizer for production of free flowing concrete or as a substantial water reducing agent for promoting high strength and durability characteristics. It is Suitable for use in tropical and hot climatic conditions.Sikament-NN complies with ASTM C-494 Type A & F.

2.6.3.3 Advantages

Sikament-NN provides the following properties

a. Reduces water requirement up to 25% (hence reducing permeability).
b. Final strength improved by up to 40%.
c. Workability is greatly improves.
d. Easy placing, less vibration.
e. Significantly reduces the risk of segregation.

2.6.3.4 Overview of Sikament-NN

Table 2.2: Overview of the properties of Sikament -NN

Property	**Detail**
Dosage	0.6% to 3% by weight of cement
Dispensing	Sikament-NN can be added to the mixing water prior to its addition to the aggregates or directly to the freshly mixed concrete (plasticizing effect is more pronounced)
Concrete Placing	Standard rules of good concreting practice must be observed
Curing	Fresh concrete must be cured properly specially at high temperatures in order to prevent plastic and drying shrinkage
Cleaning	Clean all equipment and tools with water immediately after use
Remarks	When accidental overdosing occurs, apart from retarding the initial set no detrimental effect will take place. During this period the concrete must be kept moist in order to prevent premature drying out

2.6.4 Protective Coatings

2.6.4.1 Introduction

Protective coatings are used for primary and secondary containment of liquids. Concrete is a very difficult substrate to coat properly due to its unique physical properties. For example concrete is porous, and its porosity may vary widely from one portion of the surface to another. In addition, concrete tends to contain many water and air pockets that create irregular surface characteristics. Surface irregularities, trapped air and water pockets, and expansion and contraction all contribute to the difficulty of achieving a continuous, pinhole-free coated surface. Therefore, the key to a successful coating system is to understand concrete's unique properties and adapt the system to theses constraints. Most coatings for corrosion – resistant applications have multiple components, a short pot life, limited shelf life, and are difficult to apply properly. Only experienced contractors with proven experience in the application of the specified products of concrete should be allowed to perform the work.

All surfaces exposed to earth backfill should be waterproofed since ground water could permeate the concrete through capillary action. The water permeating the concrete will eventually damage the exterior of the structure and exert vapour pressure on the interior protective coatings, causing them to disbond and fail. Waterproofing should be applied on the positive side (surface facing earth backfill) early in the construction, after construction activities that would damage the waterproofing have been completed. Generally, the components of the coating system include a primer, an intermediate (body) coat and a top coat. A primer is usually required on most coating systems and is usually considered the most component of system.

2.6.4.2 Coating Characteristics

Protective coatings are unique specifically products which represent the most widely used method for corrosion control due to seepage. They are used to give long term protection under a broad range of corrosive conditions, extending from atmospheric exposure to full immersion in strongly corrosive solutions. Protective coatings in themselves provide little or no structural strength, yet they protect other materials so that the strength and integrity of structure can be maintained. They are the skin, over the skeleton that protects and beautifies the bone and muscles of the world's essential structures.

The function of a protective coating is to separate two highly reactive materials, i.e. to prevent strongly corrosive industrial fumes, liquids, solids and gases from contracting the reactive underlying substrate of the structure. In other words they are barrier to prevent either chemical compounds or corrosion current from contacting the substrate. The physical separation is extremely important

2.6.4.3 Design Considerations

Design considerations that should help extend the life of a coating system are as follows:

a. Coat the materials that are compatible with contained liquid.
b. Compartmentalize liquids, where applicable, according to types of liquids contained. Separate acids from solvents.
c. Provide sufficient coating thickness.
d. Design the structures to limit stresses induced on the coating system.
e. Detail structures with smooth, continuous surfaces whenever possible.
f. Select chemical admixtures that will not affect the intended coating.
g. Provide structural design features such as sloped floors and sumps where applicable.
h. Provide ultraviolet protection where possible.

2.6.4.4 Selection Criteria

The reason there are so many coating systems is that there are so many different conditions where they can be used. Two key points should be kept in mind when selecting a coating system. First there is no such thing as universal coating for all conditions. Secondly almost all the coating choices represent some degree of compromise. Each coating job is unique because equipment, processes, and chemicals vary from project to project. Even identical treatment or manufacturing processes, chemicals and chemical concentrations can produce highly varied effluent. The selection process should include at a minimum, the considerations listed as follows:

a. Is the coating going to be applied on a new surface?
b. Is the coating going to be applied on an existing surface?

c. Is the coating going to be applied over an existing coating and are the two coatings compatible?
d. Is the coating going to be subject to ultra-violet exposure?
e. Is the coating going to be exposed to extremes of temperature?
f. Is the coating going to be exposed to physical contact such as forklifts, foot traffic or other items that may impact the coating?
g. If the coating will be exposed to a corrosive environment, is the exposure to fumes, splash and spill, or immersion?

One of the best reasons for selecting a particular coating system is a proven record for the intended service. Just as the contractor needs to be selected based upon successful past installations, so does the coating. Remember, success of a coating on steel does not guarantee that it will be successful on concrete.

2.6.4.5 Essential Properties of Coatings

In order to perform effectiveness, a water resistant coating must possese the following properties

a. Water resistance
b. Resistance to water absorption
c. Properties of chemical resistance
d. Proper adhesion qualities
e. Ability to expand and control
f. Weather resistance
g. Resistance to dirt pick-up
h. Resistance to bacteria and fungus

2.6.4.6 Types of coating for concrete

The concrete structures are subjected to various domestic and environmental conditions where chemical and atmospheric moisture is possible.in such situations selection of coatings become important. Commonly used coatings are:

2.6.4.7 Bituminous Cutbacks

Bituminous cutback coatings are solvent solutions of coal tar or asphalt. Both are extensively used on concrete. Coal tar cut back have better water resistance and impermeability then asphalt. On the other hand asphalt cutbacks have better weather resistance and sunlight resistance then coal tar. A thin coat generally applied as a primer followed by a heavier coat over the surface to resist water penetration.

2.6.4.8 Chlorinated Rubber Coatings

Chlorinated rubber coatings have water and chemical resistance as well as adhesion required for concrete coatings, including the all-important alkali resistance. They are lacquer type and therefore dry relatively rapidly to form a good resistant film on the surface. They have been extensively used for coating of concrete water tanks and swimming pools etc.

2.6.4.9 Vinyl Coatings

Vinyl coatings have been used for many years as coating for concrete of all types, from tank linings to nuclear energy, chemical installations and concrete floors food plants. These coatings have excellent chemical and water resistance. Vinyl coatings, because of their high molecular weight, should be preceded by a thin primer for maximum penetration into concrete surfaces. As these coatings dry rapidly, utmost care should be taken for obtaining uniform thickness.

2.6.4.10 Epoxy Coatings

Epoxy coatings have been well proven in concrete service. While all epoxy coatings adhere well to concrete surface, those one that are outstanding are those formulated with liquid epoxy resin, liquid curing agents, and highly penetrating solvents. This combination allows the epoxy resin to penetrate deeply into the concrete surface, react and increase the density as well as the strength of the surface of concrete. These coatings provide excellent water resistance to concrete surface. Used for coatings of concrete areas such as floors, tank linings, and pump base and in nuclear power plants.

2.6.4.11 Coal Tar Epoxies

Coal tar epoxies might be classed as fourth type of epoxy coatings which are uniquely applicable to concrete. These materials combine the useful properties to both the coal tar ant the epoxy into a particularly effective coating for concrete surfaces. These coatings are chemical and abrasion resistant and protect water penetration, can be used wherever black surface is applicable.

2.7 Summary

Literature review possess the unique value in research. Without this no research can be shown completed. Keeping in mind its importance we added this chapter to fulfill the requirements of our study. This chapter extensively shows the overview of the previous research done on the subject study. Previous research cannot be ignored. It poses a great deal towards our study. This provides the link between above mentioned previous research and our following study. This chapter we started it basing upon the importance of strength of concrete and following it durability of concrete. It is evident that whatever study we carry these two "must" properties of concrete should either be increased or left intact. Moreover, permeability and its ill effects are also discussed. However, factors affecting permeability of concrete are also mentioned which are catered for in the further research. Furthermore, permeability reduction measures in practice are also elaborated which laid bases for our own research procedures.

CHAPTER 3
RESEARCH METHODOLOGY AND MATERIAL TESTING

3.1 Introduction

This chapter describes the methodology used to accomplish the objectives of this research study. The chapter has been further subdivided into various sections such as research strategy, design, and description of admixtures/water proofers used in this study and the process of data analysis.

3.2 Research Strategy

Modern concrete is a sophisticated composite material which is constantly undergoing improvements and modifications. Although the basic constituents of conventional, ordinary Portland cement (OPC) concrete such as fine and coarse aggregate, cement, and water, remain the same but with the use of materials such as chemical admixtures including super plasticizers, water reducers, and air entertainers, characteristics of OPC concrete can be altered so that it may achieve the results desired by the user. While discussing the meaning of high performance concrete, Aitcin and Neville (1993) stated that "in practical application of this type of concrete, the emphasis has in many cases gradually shifted from the compressive strength to other properties of the material, such as a high modulus of elasticity, high density, low permeability, and resistance to some forms of attack."

The constituent materials of concrete should satisfy the durability, structural performance and safety requirements, taking into consideration the environment it will be subjected to. The objective of this study was to investigate the role of chemical admixtures such as water proofers and water reducers on permeability of concrete. The optimum mix proportion of admixtures is clarified for the concrete mix design. So after selecting constituents of concrete (cement, fine and course aggregate, admixtures, water proofers and surface applied chemicals), they were tested in order to ensure that they meet the relevant ASTM standards and suitable for use in mix design. Although the fine and coarse aggregate in concrete matrix act as inert filler, however aggregates petro-graphical, physical and mechanical properties can significantly affect concrete plastic and hardened characteristics. Nawy (1997) defines the most important properties of aggregate for ordinary concrete being the particle size distribution, aggregate shape, porosity and possible reactivity with cement.

Nominal mix design of 1:2:4 was selected with W/C ratio of 0.4-0.5. "Mix design is the process of selecting suitable ingredients of concrete and determining their relative quantities with the purpose of producing an economical concrete which has certain minimum properties, notably workability, strength and durability". (Neville & Brooks, 1987). Now total of 120 test samples were prepared to verify the effectiveness of different waterproofing techniques with and without addition of admixtures. ASTM C642 – 13 standard test method for density, absorption, and voids in hardened concrete, ASTM D5084 - 10 standard test methods for measurement of hydraulic conductivity of saturated porous materials and ASTM C39 / C39mstandard test method for compressive strength of concrete specimens are performed and their results are compared. Laboratory tests showed that these chemicals are efficient enough to reduce the permeability of concrete to a considerable level. This has laid the base for examining these chemicals in field conditions. "There is a radical variation in the reliability of field tests versus laboratory tests". (Wang et al., 2010). To give strong base to this study, field testing is carried out on different structures. Moreover recently a new technique has been adopted to reduce the permeability of concrete. An attempt will be made to incorporate dormant but viable bacteria in the concrete matrix which will contribute to the strength and durability of the concrete. Self-repairing concrete biologically produces calcium carbonate crystals to seal cracks that appear on the surface of the concrete structures. "An alternative design principle is that of self-healing materials, according to the concept of damage management". (Van der Zwaag 1996).

3.3 RESEARCH DESIGN

The term 'Research design' refers to methodology of doing scientific investigation by developing a plan or strategy of collecting and analysing the data (Poilt and Hungler 1985).The overall research methodology of this study is:-

3.3.1 **In preliminary study phase**, a detailed literature review has been carried out to identify the maximum possible factors causing water seepage and structural deterioration. This will be followed by description of different water reducers, water proofers, protective coatings for water proofing and membranes. Basing on the literature review suitable desire admixtures/chemical treatments are selected for this research study.

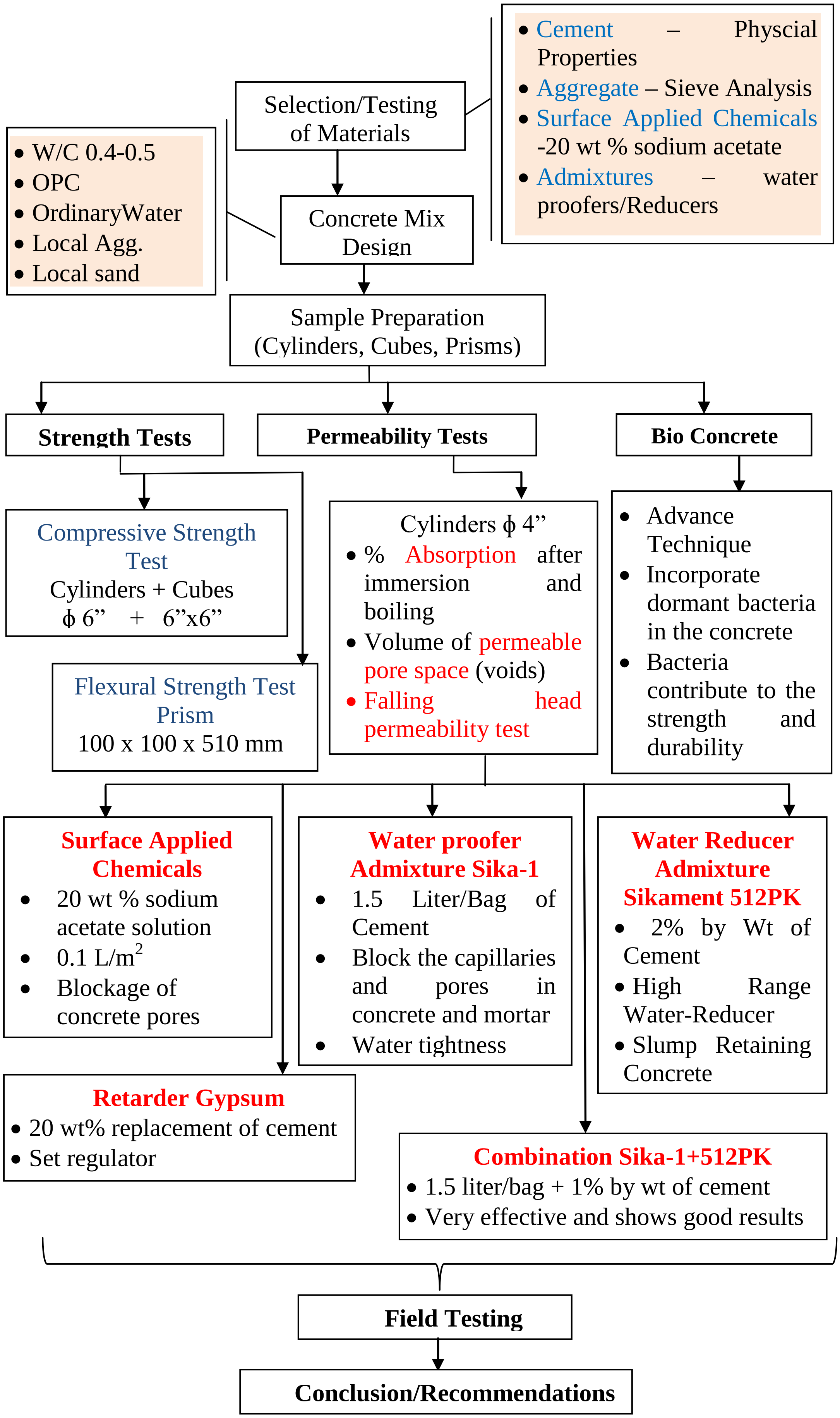
3.3.2 **In the experimental phase**, crystalline chemicals are applied on the hardened concrete, by varying composition and application rate. Moreover different admixtures/chemicals are added in fresh concrete, thus modifying the mix design, adjusting the water cement ratio and slump. In order to draw comparison, controlled samples are also cased. Samples are cured for 28 days.

3.3.3 **Laboratory Testing and Data analysis phase**, in this phase laboratory testing of samples are carried out. Strength tests and permeability tests are performed and results are analyzed using MS excel.

3.3.4 **Field Testing**, is carried out to test the suitability of admixtures under field conditions. In this regard existing structures are treated with a combination of chemicals. The problem of cold joint is also addressed, so that durable bond between old and fresh concrete can develop. Two existing structure with in MCE are selected and treated accordingly. Moreover waterproofing admixtures are also incorporated in the mix design during casting of a new structure, in order to observe the working of admixtures in real life situations.

3.3.5 **Bio-mineralization of Bacteria in Concrete,** recently an advanced technique is devised to make the concrete water proof, durable and incorporates self-healing action in concrete.

3.3.6 **Conclusions and Recommendation phase**, the findings of the study have been concluded and recommended. Best possible combinations of techniques are devised in order to reduce the permeability, using locally available admixtures. Appropriate amount of super plasticizers is identified to achieve maximum water reduction, to produce a cohesive mix with minimum voids having the desirable properties.


Selection/Testing of Materials
Cement – Physcial Properties
Aggregate – Sieve Analysis
Surface Applied Chemicals -20 wt % sodium acetate
Admixtures – water proofers/Reducers
W/C 0.4-0.5
OPC
OrdinaryWater
Local Agg.
Local sand
Concrete Mix Design
Sample Preparation (Cylinders, Cubes, Prisms)
Strength Tests
Permeability Tests
Bio Concrete
Compressive Strength Test
Cylinders + Cubes
ϕ 6" + 6"x6"
Flexural Strength Test Prism
100 x 100 x 510 mm
Cylinders ϕ 4"
% Absorption after immersion and boiling
Volume of permeable pore space (voids)
Falling head permeability test
Advance Technique
Incorporate dormant bacteria in the concrete
Bacteria contribute to the strength and durability
Surface Applied Chemicals
20 wt % sodium acetate solution
0.1 L/m2
Blockage of concrete pores
Water proofer Admixture Sika-1
1.5 Liter/Bag of Cement
Block the capillaries and pores in concrete and mortar
Water tightness
Water Reducer Admixture Sikament 512PK
2% by Wt of Cement
High Range Water-Reducer
Slump Retaining Concrete
Retarder Gypsum
20 wt% replacement of cement
Set regulator
Combination Sika-1+512PK
1.5 liter/bag + 1% by wt of cement
Very effective and shows good results
Field Testing
Conclusion/Recommendations

3.4 Selection/Testing of Materials

Concrete mix design is the science of deciding relative proportions of concrete ingredients to achieve the desired properties in the most economical way. As a matter of fact, concrete is the most frequently mentioned material in the construction industry. A good number of building failures are traceable to concrete incompetence among several other factors. "The works involved, from the design to construction stages in buildings are largely those of selecting materials, components and structures that will meet the expected building standards and aesthetics on economy basis". (Anyinuola and Olalusi, 2004). Following materials are selected for this research study and tested accordingly.

3.4.1 Cement

The cement used was a Type 1 normal Portland cement obtained from Best Way Cement Pvt. Ltd. (fineness of blaine 452 m^2/kg). The chemical composition of the cement is given in Table 4.1.

Table 3.1: Test Chemical Composition of Cement

S/No.	Constituents	Percentage %	ASTM for OPC
1.	CaO	65.4	-
2.	SiO_2	21.1	20.00 min
3.	Al_2O_3	4.44	6.00
4.	Fe_2O_3	3.68	6.00
5.	MgO	0.9	6.00
6.	SO_3	2.7	3.00
7.	LOI	1.61	3.00
9.	Free lime	1.51	2.00

Constituents of cement is shown in Table 1.1. The table presents the composition of cement with relevant ASTM requirements.

American Standard ASTM C-114 identify the amount of SiO_2 within the range not less than 20%. This minimum amount of SiO_2 is essential for silicate mineral of cement. Following tests are performed on cement.

Table 3.2:Test Physical properties of Cement

Lab Test	Details		
	ASTM Design-ation	**Apparatus**	**Description**
Standard Consistency	C 187, C 191	Vicate Apparatus, Weighing balance, Graduated glass cylinder.	Consistency is the quantity of water required to produce a cement paste which will permit the penetration of vicate plunger to a point 10mm below the original surface in 30sec after being released
Initial Setting Time	C 150	Vicate Apparatus with initial set needle and final set attachment, stop watch	Setting denotes a change in a cement paste when its fluid or plastic nature disappears. The start of this change is called “initial set” and its completion is called “final set”
Final Setting Time	-do-	-do-	-do-

3.4.2 Sand

Dry local sand was used for all samples. “Fine aggregate occupies approximately 30% of the total volume of conventional concrete, and the quality of fine aggregate affects the properties of concrete”. (CCAA&AS 2004). The recommended amount of fine aggregate in workable concrete depends on the grading of the aggregate, cement content, particle shape and grading of the coarse aggregate and intended use of concrete. The sieve analysis was performed in accordance with ASTM C136-04. Following tests are performed for physical properties of sand.

Table 3.3: Physical properties of Sand

Lab Tests	Details		
	ASTM Designation	**Apparatus**	**Description**
Fineness Modulus	C 136	Set of fine sieves, balance, mechanical shaker and camel hair brush for sieve cleaning (Sieve No. 4,8,16,30,50)	It indicates relative fineness of aggregate. It is an empirical number used to classify the concrete aggregate. FM is sum of cumulative percentages of material retained on specified sieves divided by 100. Its value varies from 2.3 – 3.1.
Bulk Specific Gravity (SSD) Bulk Specific Gravity Oven Dry Water Absorption Apparent Specific Gravity	C 128	Balance, Volumetric flask (500 ml), conical mold, tamping rod	Specific gravity values are used in mix proportioning calculations to find absolute volume that a given weight of material will occupy in the mix. In weight batching plant substituting one aggregate for another differing in specific gravity will cause a change in the yield of concrete.

3.4.3 Aggregate

Local aggregate of 3/4 - 3/16 was used. The quality of concrete chiefly depends upon the quality of aggregate because these are the aggregates that cover at least 3/4th of the total volume of concrete. The main property of concrete is strength and this property is limited by the strength of aggregates as weak aggregates can never produce strong concrete. Also the aggregate greatly influence the durability and structural performance of concrete. The coarse aggregate for concrete can be characterized by its shape, surface texture, grading, particle and bulk density, water absorption, and content of impurities and other potentially harmful materials such as silt, clay, or organic matter. Mindess (1981) states that to proportion workable, of adequate strength and durable concrete, at least the following properties of coarse aggregate must be known: shape, texture, grading, moisture content, specific gravity, and bulk density. Following tests are performed.

Table 3.4: Physical properties of Aggregate

Lab Tests	Details		
	ASTM Designation	**Apparatus**	**Description**
Fineness Modulus	C 136	Set of fine sieves, balance, mechanical shaker and camel hair brush for sieve cleaning (Sieve No. 4,8,16,30,50)	It indicates relative fineness of aggregate. It is an empirical number used to classify the concrete aggregate. FM is sum of cumulative percentages of material retained on specified sieves divided by 100. Its value varies from 2.3 – 3.1.
Bulk Specific Gravity (SSD) Bulk Specific Gravity Oven Dry Water Absorption Apparent Specific Gravity	C 128	Balance, Volumetric flask (500 ml), conical mold, tamping rod	Specific gravity values are used in mix proportioning calculations to find absolute volume that a given weight of material will occupy in the mix. In weight batching plant substituting one aggregate for another differing in specific gravity will cause a change in the yield of concrete.

3.4.4 **Water**

Ordinary water of Risalpur was used in specimen preparation and their curing. Water initiates the chemical reaction that produces the binding qualities of cement. Without it, cement is unusable powder and concrete is impossible to make.

3.5 Concrete Mix Design and Sample Preparation

Concrete mix-design means a method to choose the constituents in different amounts to achieve a durable concrete mix. The mix shall fulfil stated demands in fresh, young and hardened phase. 120 specimens are prepared with and without admixtures of 1:2:4 mix, with W/C of 0.4 – 0.5. For each concrete mixture, compressive strength, adsorption, permeability and voids were determined. The mixing is performed using laboratory concrete mixer, following mixing sequence is employed:

i. The water proofer/admixture are added to the water. Continuously stirring is done to ensure proper consistency
ii. Materials are fed in the mixture in the order of aggregate, sand and cement respectively. Small amount of water was also added with the material as per requirement.
iii. Once all the ingredients are added, water is slowly introduced and the mix was allowed to attain required workability and consistency.
iv. Moulds are cleaned and coated inside lightly with oil, then placed on a clean, level and firm surface.
v. Specimens were fill 1/3 the volume of the mould with concrete then compacted by rodding and then they are compacted by vibrating using a vibrating table.
vi. Level off the top with the steel rod and clean any concrete from around the mould.
vii. Slump is measured according to ASTM C143-12 Standard Test Method for Slump of Hydraulic-Cement Concrete.

Figure 3.1 : Slump Measurement

3.5 Strength Tests

Concrete mixes can be designed to provide a wide range of mechanical and durability properties to meet the design requirement of a structure. The strength of concrete is most importance performance measure used by engineer in designing buildings and other structures. Compressive and flexural testing is performed after 28 days curing according to ASTM C31, making and curing concrete specimens in the field.

3.5.1 Standard Test Method for Compressive Strength of Concrete Specimens (ASTM C39 / C39M)

The compressive strength is measured by breaking specimens in a compression testing machine. The compressive strength is calculated from failure load divided by cross sectional area resisting the load and reported in units of pound –force per square inch (psi). Concrete compressive strength requirements can from 2500 psi for residential concrete to 4000 psi and higher in commercial structures. Most concrete structures are designed under assumption that the concrete resist compressive stresses but not tensile stresses, hence for purposes of structural design the compressive strength is the criterion of quality (Troxell et al., 1968).

3.5.1.1 Scope

This test method covers determination of compressive strength of cylindrical concrete specimenssuch as molded cylinders and drilled cores. It is limited to concrete having a unit weight in excessof 800 kg/m^3 (50 lb/ft^3).

3.5.1.2 SUMMARY OF METHOD

This method consists of applying a compressive axial load to molded cylinders or cores at a rate which is within a prescribed range until failure occurs. The compressive strength of the specimen is calculated by dividing the maximum load attained during the test by the cross-sectional area of the specimen.

3.5.1.3 Overview of Standard Test Method for Compressive Strength of Concrete Specimens (ASTM C39 / C39M)

Table 3.5: Details of the ASTM C39 / C39M

Overview of the ASTM C39 / C39M Standard Test Method for Compressive Strength of Concrete Specimens	
SIGNIFICANCE AND USE	Care must be exercised in the interpretation of the significance of compressive strength. Test values obtained will depend on the size and shape of the specimen, batching and mixing procedures. The results of this test may be used as a basis for quality control of concrete proportioning, mixing, and placing operations.
Placing the Specimen	Place the plain (lower) bearing block, with its hardened face up, on the table or platen of the testing machine directly under the spherically-seated (upper) bearing block
Zero Verification	Prior to testing the specimen, verify that the load indicator is set to zero. In cases where the indicator is not properly set to zero, adjust the indicator
Rate of Loading	The load shall be applied at a rate of movement (platen to crosshead measurement) corresponding to a stress rate on the specimen of 0.25 ± 0.05 MPa/s (35 ± 7 psi/s).
Calculation	Calculate the compressive strength of the specimen by dividing the maximum load carried by the specimen during the test by the average cross-sectional area

3.5.2 Flexural Strength of Concrete Specimens

Prisms are tested for flexure in Universal testing machine of capacity 100 kN. The bearing surfaces of the supporting and loading rollers are wiped clean before loading. The prisms are placed in the machine in such a manner that the load is applied to the uppermost surface along the two lines spaced 13.3 cm apart. The axis of the specimen is aligned with the axis of the loading device. The load is applied at a rate of 180 kg/min without shock. The specimen is loaded till it fails and the maximum load (P) applied to the specimen during test is noted. After fracture the distance (a) between the crack and nearest support is measured. The flexural strength of the specimen is expressed as the modulus of rupture:

$$\mathbf{f_b} = \frac{PL}{bd^2} \text{ when, a is greater than 13.3 cm or}$$

$$\mathbf{f_b} = \frac{3Pa}{bd^2} \text{when a is in between 11.0 cm and 13.3 cm}$$

Where,

a = the distance between the line of fracture and the nearest support.

b = measured width in cm of the specimen,

d = measured depth in cm of the specimen was supported, and

P = maximum load in kg applied on the specimen.

If a is less than 11.0 cm the test result is discarded

3.6 Permeability Tests

It is now well recognized that concrete durability is to a great extent governed by its permeability. A decrease in permeability reduces deterioration of concrete due to factors such as freezing and thawing, alkali-aggregate reaction, carbonation, etc. "In general, use of fly ash or other mineral admixtures causes pore as well as grain refinement which leads to reduced permeability". (Mehta 1989). For this study permeability tests is carried out to evaluate the influence of addition of admixtures on concrete permeability. Permeability of concrete plays an important role in durability because it controls the rate of entry of moisture that may contain aggressive chemicals and the movement of water during heating or freezing. Higher the permeability lesser will be the durability. Permeability of concrete is of interest also in relation to the water-tightness of liquid-retaining structures. Higher the permeability lesser will be the water-tightness. Following tests are performed to evaluate permeability of concrete.

3.6.1 Standard Test Method for Density, Absorption, and Voids in Hardened Concrete (ASTM C642–13)

3.6.1.1 Scope

This test method covers the determinations of density, percent absorption, and percent voids in hardened concrete. This standard is issued under the fixed designation C642; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision.

3.6.1.2 Apparatus

i. Balance, sensitive to 0.025 % of the mass of the specimen.
ii. Container, suitable for immersing the specimen and suitable wire for suspending the specimen in water.

3.6.1.3 Test Specimen

Whenever possible, the sample shall consist of several individual portions of concrete, each to be tested separately. The individual portions may be pieces of cylinders, cores, or beams of any desired shape or size, except that the volume of each portion shall be not less than 350 cm^3 (or for normal weight concrete, approximately 800 g); and each portion shall be free from observable cracks, fissures, or shattered edges.

3.6.1.4 Procedure

i. **Oven-Dry Mass.** Determine the mass of the portions, and dry in an oven at a temperature of 100 to 110°C for not less than 24 h. After removing each specimen from the oven, allow it to cool in dry air (preferably in desiccators) to a temperature of 20 to 25°C and determine the mass. If the specimen was comparatively dry when its mass was first determined, and the second mass closely agrees with the first, consider it dry. If the specimen was wet when its mass was first determined, place it in the oven for a second drying treatment of 24 h and again determine the mass. If the third value checks the second, consider the specimen dry. In case of any doubt, re dry the specimen for 24-h periods until check values of mass are obtained. If the difference between values obtained from two successive values of mass exceeds 0.5 % of the lesser value, return the specimens to the oven for an additional 24-h drying period, and repeat the procedure until the difference between any two successive values is less than 0.5 % of the lowest value obtained. Designate this last value A.

ii. **Saturated Mass after Immersion**. Immerse the specimen, after final drying, cooling, and determination of mass, in water at approximately 21°C for not less than 48 h and until two successive values of mass of the surface-dried sample at intervals of 24 h show an increase in mass of less than 0.5 %of the larger value. Surface-dry the specimen by removing surface moisture with a towel, and determine the mass. Designate the final surface-dry mass after immersion B.

iii. **Saturated Mass after Boiling.**Place the specimen, processed as described, in a suitable receptacle, covered with tap water, and boil for 5 h. allow it to cool by natural loss of heat for not less than 14 h to a final temperature of 20 to25°C. Remove the surface moisture with a towel and determine the mass of the specimen. Designate the soaked, boiled, surface-dried mass C.

iv. **Immersed Apparent Mass**. Suspend the specimen, after immersion and boiling, by a wire and determine the apparent mass in water. Designate this apparent mass D.

3.6.1.5 Calculation

By using the values for mass determined in accordance with the procedures described in Section 5, make the following calculations:

i. Absorption after immersion, % = $\left[\frac{B-A}{A}\right] x 100$ (3.1)

ii. Absorption after immersion and boiling, % = $\left[\frac{C-A}{A}\right] x\ 100$ (3.2)

iii. Bulk density, dry = $\left[\frac{A}{C-D}\right] x\ \rho = g_1$ (3.3)

iv. Bulk density after immersion = $\left[\frac{B}{C-D}\right] x\ \rho$ (3.4)

v. Bulk density after immersion and boiling = $\left[\frac{C}{C-D}\right] x\ \rho$ (3.5)

vi. Apparent density = $\left[\frac{A}{A-D}\right] x\rho = g_2$ (3.6)

vii. Volume of permeable pore space (voids), % = $\left[\frac{g2-g1}{g2}\right] x\ 100$ (3.7)

Where:

A = mass of oven-dried sample in air, g

B = mass of surface-dry sample in air after immersion, g

C = mass of surface-dry sample in air after immersion and boiling, g

D = apparent mass of sample in water after immersion and boiling, g

g_1 = bulk density, dry, mg/m^3 and

g_2 = apparent density, mg/m^3

ρ = density of water = 1 mg/m^3 = 1 g/cm^3.

3.6.2 Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials (ASTM D5084-10)

The notion of permeability has been mostly developed in soil mechanics to evaluate the ease with which fluid moves through the 70 tortuous path of a solid skeleton with interconnected voids (Das 2010). Such measurement can be used for stability analyses of earth and retaining structures, and to estimate the quantity of underground seepage under various hydraulic conditions.The value of k (cm/s) is basically deduced from the measured percolatingflow rate (Q, cm^3/s) through a specimen.During the dormant period of cement hydration, fresh mortarsor concrete behave as weakly bonded materials submerged in fluid medium, and thus can be regarded as soil (Alexandridis and Gardner 1981; Assaad and Harb 2011). Therefore in this research paper, falling head permeability test is used to assess permeability of fresh concrete. The falling-head test is suited for testing fine grained soils where the k value is expected to be within the range of 10^{-5} to 10^{-8} cm/s, or when the soil contains 10% or more particles passing the 75-μm sieve. Therefore, the falling-head method was selected in this study for testing concrete.

3.6.2.1 Apparatus

The permeameter stand consisted of a metal frame with burette adjustable in height between 1,500 and 4,500 mm. This allowsmonitoring the extent of hydraulic gradient applied on top of thetested specimen. After opening the inlet water valve on top of the cell, outflow is observed in samples. The value of k was determined as follows:

$$k \text{ (cm/sec)} = \frac{a}{A} \, x \, \frac{L}{\Delta t} \, x \, \ln \left[\frac{h1}{h2} \right] \qquad (3.8)$$

Where

a (cm^2) = cross-sectional area of the inlet water valve,

A (cm^2) = cross-sectional area of specimen,

L (cm) = height of specimen, and

Δt (s) = time needed for the total head to drop from clearly marked graduations h_1 to h_2 (Fig.4).

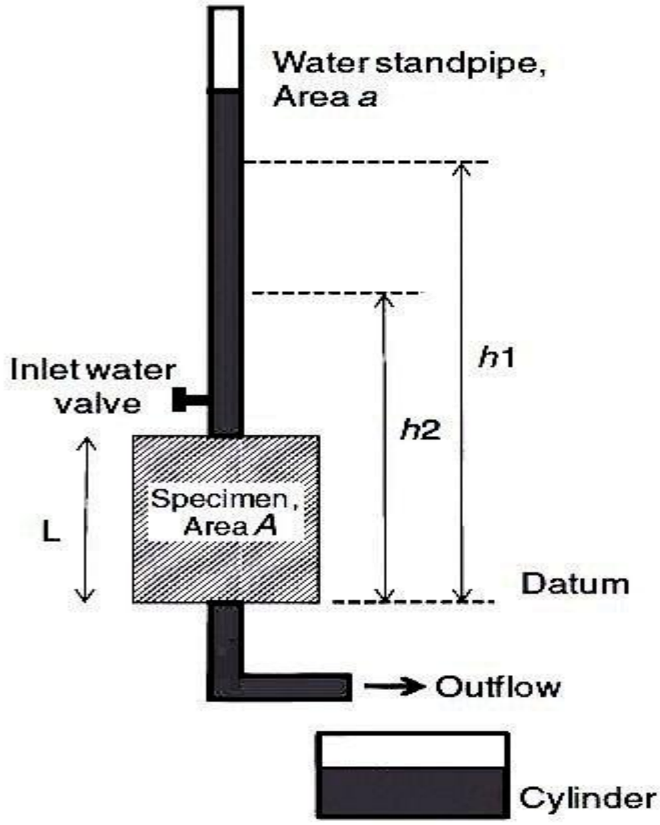


Figure 3.2: Sketch for the Permeability Test, Falling-Head Method

3.7 Chemicals/Admixtures used in this research study

Following are the selected admixture/chemicals that are used in this research study. Their working, mechanism and properties are described below.

3.7.1 Crystallization Technology for Reducing Water Permeability into Concrete

3.7.1.1 Introduction

Various systems are currently used to prevent or minimize water penetration into concrete, to avoid the previously mentioned water-associated problems of the concrete. Barrier systems are the most-used system to prevent water penetration. These systems are mainly polymeric systems (epoxy resin, acrylic resins, bitumen systems, etc.). They can be installed on the positive or negative side of the water pressures. A comprehensive study on the effectiveness of such systems has been presented by Barbucci et al. Barrier systems can be very successful in preventing water penetration. However, other factors can jeopardize the selection of these barrier systems. The resistance of these systems to acidic attacks or sulfate attacks, the adhesion of these systems to different concrete substrates, service life, and economic factors are among the selection criteria that barrier systems may fail. A major drawback on barrier systems is the one-sided protection. Penetration of water from different sides of the concrete and through joints may cause these systems to fail to protect concrete substrates.

Silicate solution (mainly, sodium silicate) has been used extensively in the market for the purpose of waterproofing. It is well-known now that the greatest problem associated with the use of silicate solutions lies in the actual chemical reaction process that creates the gel structure within the concrete. This gel will absorb internal moisture from the concrete and begin to swell. This swelling will continue whenever moisture becomes available. The swelling would produce extreme internal pressures and stresses, even to a point where the concrete's integrity can and will be damaged quite severely. After the gel reaction begins to swell from excess water of convenience, the resulting failure of the top layer of concrete will cause delimitation of the surface of the concrete. Silicate solution works in a similar way, damaging the concrete.

Other disadvantage of using silicate solution is that the pH of the concrete must be at certain levels to work as a waterproofing sealer. This pH level is determined by the amount of free calcium hydroxide that reacts with the silicate. Silane/ siloxane products are also considered one of the most used waterproofing materials for large concrete structures, such as airports, bridges, and marine applications. It is dependent on its moisture-repellent nature to minimize the water penetration into concrete. Most of these products are solvent-based materials, and the silane itself has raised many questions regarding the environmental impact. The increasing environmental concerns has forced contractors to find alternative products that have less environmental impact, because of the use of solvent-based products. In addition, the application of silane to the concrete requires that the moisture content of the concrete be low enough to apply this water-repelling product

3.7.1.2 The New Technology

A new water-based crystallization technology to minimize the water-related problems of concrete is used in this study. This technology is dependent on the formation of sodium acetate crystals inside the pores of the concrete after concrete spray treatment with its aqueous solution. Results have indicated a significant reduction in water permeability, as a result of concrete treatment with this solution after full curing. The core of this technology is based on the formation of a salt solution of sodium acetate, which can be produced via many methods but mainly through the reaction of acetic acid and sodium carbonate (soda ash), according to the following reaction:

$$Na_2CO_3(s) + 2CH_3COOH\ (l) \longrightarrow 2CH_3COONa(s) + H_2O\ (l) + CO_2\ (g)$$

Different salts were considered before this salt was selected. Among them were sodium tartarate, sodium citrate, and sodium carbonate. The salt of sodium acetate is used, because the rate of crystal growth is high, compared to other salt that has been studied. Sodium acetate penetrates inside the pores of the concrete. After the introduction of water, crystals start to grow, which leads to blockage of concrete pores and, therefore, reduced water permeability. The crystal of sodium acetate is a hygroscopic crystal. This would help in absorbing excess moisture in the surroundings of the concrete pores. Sodium acetate can still hold a considerable amount of water, depending on the surrounding humidity. Small quantities (1%) of isopropanol were added to the solutions used in this study, to reduce the surface tension of this solution and help penetration into the concrete substrate.

3.7.1.3 Procedure for Surface Treated Samples

After full curing for 28 days according to the ASTM C39 standards, the controlled samples are treated with the optimum solution of 20 wt % sodium acetate, using a typical paint brush. The application rate was approximately 0.1 L/m^2. One week after treatment, the water adsorption test and permeability test were performed to know the effectiveness of surface treatment.

Figure 3.3: Sodium Acetate Preparation and Application on Samples

3.7.2 Waterproofing Admixture for Concrete & Mortar Sika-1

3.7.2.1 Product Description

Sika-1 is normal setting water proofer, the action of which is to block the capillaries and pores in concrete and mortar. While blocking the passage of water it allows the structure to breathe, thus considerably reducing the possibility of condensation. Suitable for use in tropical and hot climatic conditions.

3.7.2.2 Uses

Sika-1is the basis of the internationally known Sika Structural Waterproofing System, which is completely suited to most types of brick and concrete structures subjected to water pressure and dampness both internal and external sources. Sika renderings are applied in two, three or four coats depending on the water pressure being dealt with and the structure involved. The standard rendering, however, normally consists of three coats.

3.7.2.3 Product Data

Table 3.6: Properties of Sika-1

Property	Characteristics
Type	Specially Selected Chemical Composition
Form	Yellow Liquid
Packaging	5lt. and 25lt. pails, 200 lt. drums and 1000 lt. flow bins
Storage Condition	Store in a dry area between 5ºC and 35ºC. Protect from direct sunlight
Shelf life	12 months minimum from production date if stored properly in original unopened packaging
Density	Approximately 1.0 kg/lt.
Freezing Point	00 C
Chloride content	Nil (EN 934-2) Sika® -1 1/6

3.7.2.4 Application Details

Table 3.7: Application Details of Sika-1

Job	No. Of Coats (min)	Thickness (mm)	Dosage (per liter)
Wall renderings (> 3m)	3	25	1.3 - 1.5 m^2
floor toppings (> 3m)	3	38	1.0 - 1.3 m^2
Wall renderings (< 3m)	3	20	1.8 - 2.4 m^2
floor toppings (< 3m)	2	13	2.6 - 3.0 m^2
General Water proofer	3.0 liters per 100 kg of cement		
Watertight concrete	9 liters of Sika®-1 per m3 concrete		

Note: Trial mixes should always be conducted to establish the exact water requirements per mix.

3.7.2.5 Mixes

i. For all uses with mortar, dilute one part Sika-1 with 10 parts clean water (with wet sand 1:8, with dry sand 1:12). Stir the mixture often and use within 12 hours.
ii. For watertight concrete, Sika-1 can be added neat provided that the concrete is well mixed to achieve a homogeneous consistency.
iii. Sika-1 is a yellow liquid and the solution must be free from lumps before use.
iv. To ensure this, first mix equal quantities of Sika-1 and water slowly, stirring all the time.

3.7.2.6 Sika-1 rendering to resist moisture and dampness above ground level

i. Prepare the surface as previously mentioned.
ii. Apply the first coat of a mortar (cement: sand = 1:1) waterproofed with Sika-1at not less than 6 mm thick, taking care to cover the whole surface.
iii. Mix to a sloppy consistency and cast on vigorously.
iv. Apply the second coat of Sika-1mortar at not less than 6 mm, as soon as the previous coat has stiffened sufficiently (usually after 4-5 hrs.).
v. The second coat should be a mortar (cement: sand = 1: 2.5) applied with a wood float finish.
vi. Sika-1 : Water = 1 : 10

Dilution of Sika-1: Water = 1: 10

3.7.3 Sikament 512PK High Range Water-Reducing and Slump Retaining Concrete Admixture

3.7.3.1 Product Description

Sikament 512PK is highly effective dual action liquid super plasticizer for the production of free flowing concrete or as a substantial water-reducing agent for promoting high strengths. It imparts excellent slump retention for prolonged periods. The product is suitable for use in tropical and hot climatic conditions.

3.7.3.2 Uses

Sikament 512PK is used as a super plasticizer in the production of free flowing concrete such as

a. Slabs and foundation
b. Walls , columns and piers
c. Slender components with densely packed reinforcement
d. Piles

It is also used as a water-reducing agent for production of high early strength concrete such as

a. Pre-cast concrete elements
b. Pre-stressed concrete
c. Bridges and cantilever structures

3.7.3.3 As a Super plasticizer

a. Workability is greatly improved
b. Concrete is placed easily, especially suitable in slender components with densely packed reinforcement
c. Concrete requires less vibrating
d. Improved cohesion of concrete mix reduces significantly the risk of segregation and allows greater time for placement.

3.7.3.4 As a Water-Reducer

a. Up to 20% water reduction
b. Final strength improved up to 40%

3.7.3.5 Product Data

Table 3.8: Properties ofSikament 512PK

Property	Characteristics
Type	Sulphonated naphthalene based polymer
Form	Brown Liquid
Packaging	200 lt. drums and 1000 lt. flow bins
Storage Condition	Store in a dry area between 5ºC and 35ºC. Protect from direct sunlight
Shelf life	12 months minimum from production date if stored properly in original unopened packaging
Density	Approximately 1.17 to 1.19 kg/lit
Chloride content	Nil (EN 934-2)

3.7.3.6 Application Details

Recommended dosages: 0.6-2.0% by weight of cement. It is advisable to carry out trials mixes to establish the correct dosage. However, higher dosages can be used in combination with sika fumes.

3.7.3.7 Dispensing

Sikament 512PK can be added to the mixing water prior to its addition to the aggregates or directly to the freshly mixed concrete (the plasticizing effect is more pronounced). For Ready-mix concrete, Sikament 512PK is added to the concrete immediately prior to discharge and after further mixing has taken place for at least three minutes.

3.7.4 Gypsum

3.7.4.1 Introduction

Gypsum has been recognized as a valuable building material for several thousand years. The Greeks and the Egyptians both used it to advantage in structures which still stand. Gypsum usually is found in rock formation in various parts of the world, notably in Canada, United States, France, England, Italy, China, Russia and areas of South America. The rock is crushed, ground and calcined (heated), which drives off about 75 percent of the combined water, forming the hemihydrate known as plaster of Paris. If this product is mixed with water, a chemical recombination takes place and the original rock structure is reformed. Gypsum is a hydrous calcium sulfate with the chemical formula $CaSO_4$ ($2H_2O$), which means that it is a compound of lime, sulfur, and water.

Gypsum is soluble in hydrochloric acid and also in about 500 parts of water; its specific gravity is 2.3. Anhydrite, calcium sulfate without combined water ($CaSO_4$), is often found closely associated with gypsum

3.7.4.2 The Influence Of Gypsum On The Properties Of Portland Cement Pastes

Gypsum plays a crucial role in cement. Though it is used in a small quantity, in the range of 2.5-3.0 percent in terms of SO3, gypsum's role in cement is significant, more predominantly at early ages. Gypsum renders workability to mortar or concrete by keeping the cement in plastic state at early age of hydration. This is achieved by changing the course of hydration of calcium aluminates that manifests as retardation in cement hydration. This is how gypsum is identified as a set regulator or retarder, as known popularly. Nevertheless, gypsum also contributes for strength acceleration in the early stages of hydration. Gypsum is the set retarder for ordinary Portland cement (OPC). Without gypsum, ground clinker exhibits flash setting in a few minutes, due to the rapid hydration of calcium aluminates to form calcium aluminate hydrate (CAH). The hydration of C_3A releases profuse exothermic heat making the matrix stiff, minimizing the chances for remixing. The CAH, thus formed, does not contribute for strength of the matrix and, moreover, hampers the hydration of calcium silicate. The sequence of reactions, in the absence of gypsum, totally vetoes the commercial use of cement. The following chemical reaction, in the absence of gypsum, is explanatory in this regard.

$3CaO.\ Al_2O_3 + n\ H_2O$ (fast reaction) $\longrightarrow$ CAH + profuse exothermic heat

Hence, it was found essential to change the reaction course of C3A, and this was met by the use of sulphate salts. Due to its affinity with SO3, aluminate tends to react readily with the former and in this process the reactions of aluminate with water are prevented. Ultimately, gypsum was identified as the most effective form of sulphate to control hydration reactions of C_3A that incidentally resulted in better workability for a longer duration. Chemical reaction in the presence of gypsum is given below

$$3CaO.\ Al_2O_3 + 3CaSO_4.\ 2H_2O + nH_2O \longrightarrow 3CaO.\ Al_2O_3.\ 3CaSO_4.\ 32H_2O$$

(Ettringite: calcium trisulpho aluminate hydrate) + moderate exothermic heat

Many in the cement and concrete industry know the role of gypsum as set retarder or set regulator. But the complementary role of gypsum, as accelerator to render high early strengths, is generally unnoticed. This knowledge gap lead to a misunderstanding that the addition of more gypsum means additional retardation in setting, which is not true. The formation of ettringite at threshold levels accelerates the hardening process and thus hastens strength gain at early ages.

3.8 Summary

On the basis of detailed study of the properties of the different admixtures and their local availability, few are selected for further research.

Table 3.9: Overview of Waterproofing Agents

Technique	Concrete State	Function
Crystalline Water Proofing	Hardened	Blocks the capillary pores
Water Proofer SIKA-1	Fresh and Hardened	Blocks the capillary pores
Water Reducer Sikament 512 PK	Fresh	Reduces water requirement of the mix design
Gypsum	Fresh	Regulate the setting time of cement, reduce the water demand of the mix
Bio-mineralization of Bacteria in Concrete	Fresh	produces calcium carbonate crystals to seal cracks that appear on the surface of the concrete structures

This chapter provides the research strategy that is followed during the course of this research. It provides the extensive research design that is framed after due consideration and under advisors instructions. It provides laboratory test procedures and methods for analysis of obtained data. We ought to follow the best devised procedure for our research. Initially material testing is described i-e for which material which tests are to be performed to examine them and declare them fit or unfit for the purpose of study. After material testing, procedure for preparation of different type'ssamples in different phases is discussed. This also includes the study of mix design that is used in preparation of concrete samples. Following these steps strength test of samples is conducted to ensure that our research do not affect the integrity of concrete. Test for reduction of permeability also forms the part of the chapter. After the obtained results from reduction measures, the procedure to analyse these results is also mentioned in it.

CHAPTER 4
RESULTS AND ANALYSIS

Introduction

Excellent long-term performance of concrete structures is associated with both concrete strength and durability properties, e.g., Permeability which is a governing property to estimate durability of a concrete structure. In order to know the effectiveness of various suggested methods of water proofing against water penetration, detailed laboratory testing is conducted. Different modified samples are prepared and their water absorption is measured against the controlled samples. Moreover hydraulic conductivity of all the samples is measured and effectiveness of different mixes is observed.

4.1 Material Testing

Concrete is a composite material made by mixing coarse and fine aggregates, cement, water and at times admixtures are also essential when special properties are desired. Performance of concrete depends on the quality of the constituent materials as well as on their proportion and on the class of construction that comprises: placing, compaction, and curing. Hence, to discuss about the performance of concrete it is mandatory to learn about the concrete making materials and some other factors affecting this performance.

4.1.1 Cement

The cement used was a Type 1 normal Portland cement obtained from Best Way Cement Pvt. Ltd. (fineness of blaine 452 m^2/kg).

Table 4.1: Properties of Cement

Lab Test	Values	ASTM Specifications
Standard Consistency	24	20-26%
Initial Setting Time	120	60 Min (min)
Final Setting Time	480	375 Min (max)

4.1.2 Sand

Dry local sand graded between 0.5 mm (No.35) sieve and 0.074 mm (No. 200) was used for all samples. The sieve analysis was performed in accordance with ASTM C136-04. Physical properties of sand are listed in table 4.3 below.

Table 4.2: Physical Properties of Sand

Properties	Local Sand
Fineness Modulus	2.01
Bulk Specific Gravity (SSD)	2.655
Bulk Specific Gravity Oven Dry	2.612
Water Absorption	1.5
Apparent Specific Gravity	2.23

Fineness modulus FM indicates relative fineness of aggregate. It is an empirical number used to classify the concrete aggregate. It is sum of cumulative percentages of material retained on specified sieves divided by 100.

Table 4.3: Results of Sieve Analysis of Fine Aggregate

Sieve #	Mass Retained (gm.)	% Retained	Cumulative % Retained	Cumulative % Passing
3/16	-	0	0	100
7	2	0.6	0.6	99.4
14	16	4.87	5.47	94.53
25	84.3	25.67	31.14	68.86
52	134.5	40.97	72.11	27.89
100	66.5	20.26	92.37	7.83
Pan	5	1.52	100.0	0

$$\textbf{FM} = \frac{\sum(\textbf{Cummulative \% retained on standard sieve of 150µm or above})}{\textbf{100}}$$

$$\textbf{FM} = \left[\frac{(92.37+72.11+31.14+5.47+0.6)}{100}\right] = 2.01.$$

4.1.3 Aggregate

Aggregate is one of the main ingredients in producing concrete. It covers 75% of the total for any concrete mix. The strength of the concrete produced is dependent on the properties of aggregates used.

Table 4.4: Physical Properties of Aggregate

Properties	**Aggregate**
Relative Density (Specific gravity) and Water Absorption of the Coarse Aggregate	0.63%
Fineness Modulus	2.573
Impact Value	19.3%
Water Absorption	1.5
Apparent Specific Gravity	2.23

Table 4.5: Results of Sieve Analysis of Coarse Aggregate

Sieve #	**Mass Retained (gm.)**	**% Retained**	**Cumulative % Passing**
3/4	43	1.04	98.96
1/2	1095	26.46	72.5
3/8	1190	28.76	43.74
3/16	1633	39.47	4.74
PAN	176	4.25	0

4.2 Samples Preparation

4.2.1 Mix Proportions

Mix proportions given in table 16 were used for making specimens for different sets of experiments; these proportions were finalized while aiming for compressive strength above 2500 psi with nominal mix design of 1:2:4, as it is commonly used throughout Pakistan. Admixtures and water proofers are added to obtain the desired workability and watertight concrete.

Table 4.6: Mix Proportions

Samples	Nominal Mix Proportion 1:2:4		
	Water/Cement Ratio, by weight	**Admixture/Water Proofer**	**Quantity of Admixture/Water Proofer**
ControlledSamples	0.65	-	20-26%
Modified Sample-I	0.42	Sika-1	1.5liter/Bag of Cement
Modified Sample-II	0.42	Sikament 512PK	1.8% by weight of Cement
Modified Sample-III	0.42	Sika-1+Sikament 512PK	1.5liter/Bag of Cement + 1% by weight of Cement respectively
Modified Sample-IV	0.42	Gypsum	25% by wt. replacement of cement

4.2.2 Samples

Specimens including cubes, prisms and cylinders are casted in order to measure the efficiently of different water proofing techniques and flexural and compressive strength of specimens.

Table 4.7: Samples Description

Samples			
Cubes		**Cylinders**	**Prisms**
Sizes	6”x6”	6”/4”Dia	100 x 100 x 510 mm
			

4.3 Sample Designation and Details

Table 4.8:Sample Designation and Details

Designation and Details	Abbreviation
Controlled Concrete Samples	CS
Samples with Sika-1	S1
Samples with Sikament 512PK	PK
Samples with gypsum	G
Samples with Sika-1 + 512PK	S1+PK
Surface Treated Samples	ST
Field Samples	F

4.4 Strength Tests

Since the primary function of practically all structures is to carry loads or resist applied forces of whatever nature, concrete used for such purposes must have strength. This is the reason why the strength of concrete is commonly considered its most valuable property, although in some cases other characteristics may be more important. Nevertheless, strength usually gives an overall picture of the quality of concrete, and it is considered as good index whether direct or inverse, of most of the other properties. Strength usually gives an overall picture of the quality of concrete, and it is considered as good index whether direct or inverse, of most of the other properties (Mikyas 1987).

4.9: 28 Days Compressive Strength Test Results

Samples	28 Days Compressive Strength f'c (psi)		Flexural Strength (N/mm^2)
	Cylinders	Cubes	Prisms $f_b = \frac{PL}{bd^2}$
CS	2800	3600	1.5
S1	3300	4080	2.0
PK	5000	6180	1.8
G	2950	3550	1.6
S1+PK	4400	5350	2.2

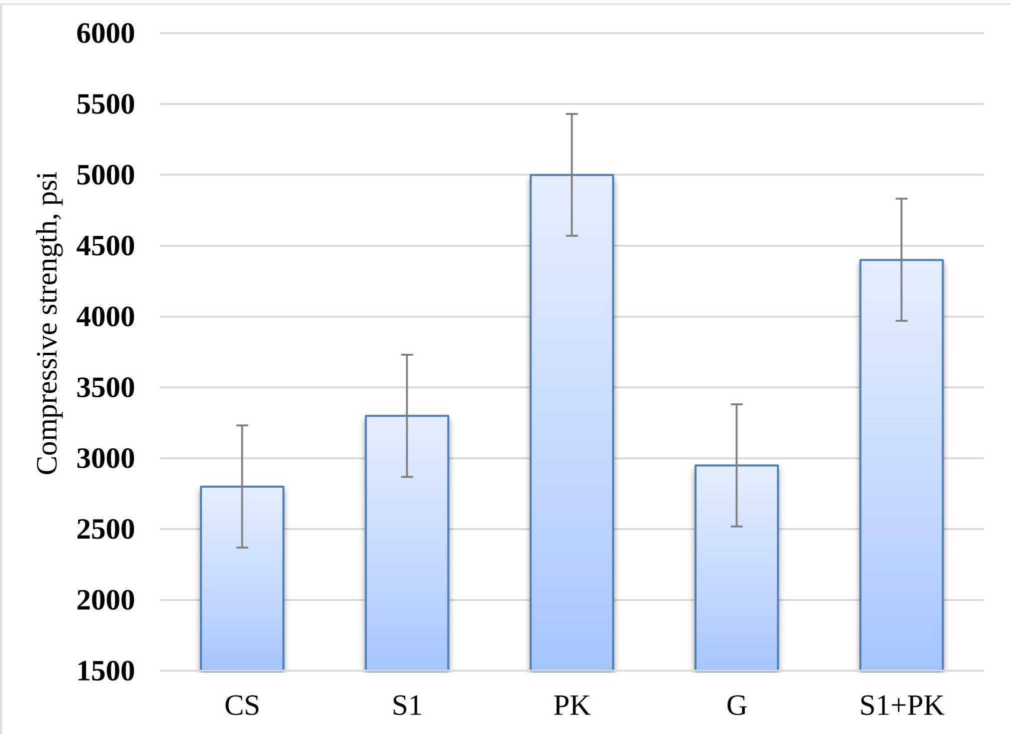


Figure 4.1: 28 Days Compressive Strength of Cylinders

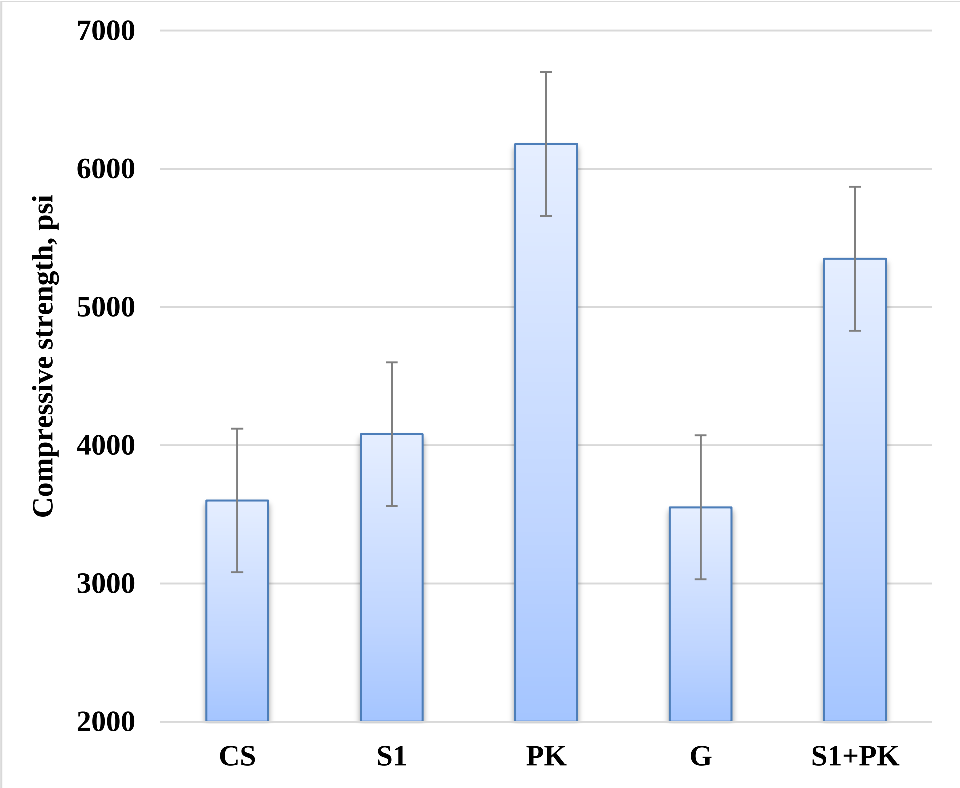


Figure 4.2: 28 Days Compressive Strength of Cubes

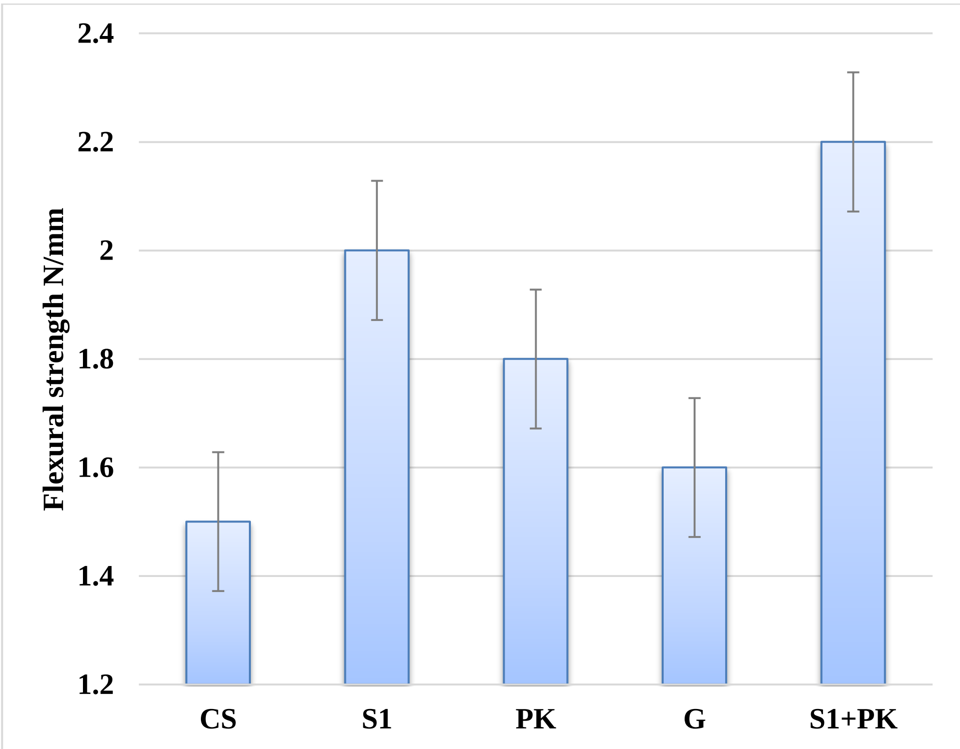


Figure 4.3: Flexural Strength of Prisms

4.5 PERMEABILITY TESTS

A concrete structure is considered to be of adequate durability if it performs in accordance with its intended level of functionality and serviceability over an expected or predicted life cycle. Durable concrete must have the ability to withstand the potentially deteriorative conditions to which it can reasonably be expected to be exposed.

In terms of deterioration of concrete due to physical or chemical causes, the mobility of fluids or gases through the concrete are nearly always involved. The overall susceptibility, or penetrability of a concrete structure, especially when compounded by additional environmental or exposure challenges, is the key to its ultimate serviceability and durability. Low porosity / permeability / penetrability of concrete to moisture and gas is the first line of defence against: frost damage, acid attack, sulfate attack, corrosion of steel embedment and reinforcements, carbonation, alkali-aggregate reaction, and efflorescence to name a few of the most prominent concrete ailments. Concrete durability is significantly affected by its permeability. Concrete is a porous material. Therefore, moisture movement can occur by flow, diffusion, or absorption.

It is now well recognized that concrete durability is to a great extent governed by its permeability. A decrease in permeability reduces deterioration of concrete due to factors such as freezing and thawing, alkali-aggregate reaction, carbonation, etc. "In general, use of fly ash or other mineral admixtures causes pore as well as grain refinement which leads to reduced permeability". (Mehta, 1989). Following tests are conducted to know the permeability of concrete specimens containing different chemicals/admixtures.

4.5.1 Standard Test Method for Density, Absorption, and Voids in Hardened Concrete(ASTM C642 – 13)

4.5.1.1.1 Data

i. A = mass of oven-dried sample in air, g
ii. B = mass of surface-dry sample in air after immersion, g
iii. C = mass of surface-dry sample in air after immersion andboiling, g
iv. D = apparent mass of sample in water after immersion and boiling, g
v. g1 = bulk density, dry, mg/m3 and
vi. g2 = apparent density, mg/m3

vii. ρ= density of water = 1 mg/m^3 = 1 g/cm^3

viii. Total volume of specimen (including solids, "permeable" voids, and "impermeable" voids) = $V = \pi r^2$ x h = π x 2^2 x 6 = 75.4 in^3 = 1236.5cm^3

Note: All calculations are shown in appendix A.

4.5.1.1.2 Adsorption after Immersion

Absorption after immersion, % = $\left[\frac{B-A}{A}\right] x\ 100$

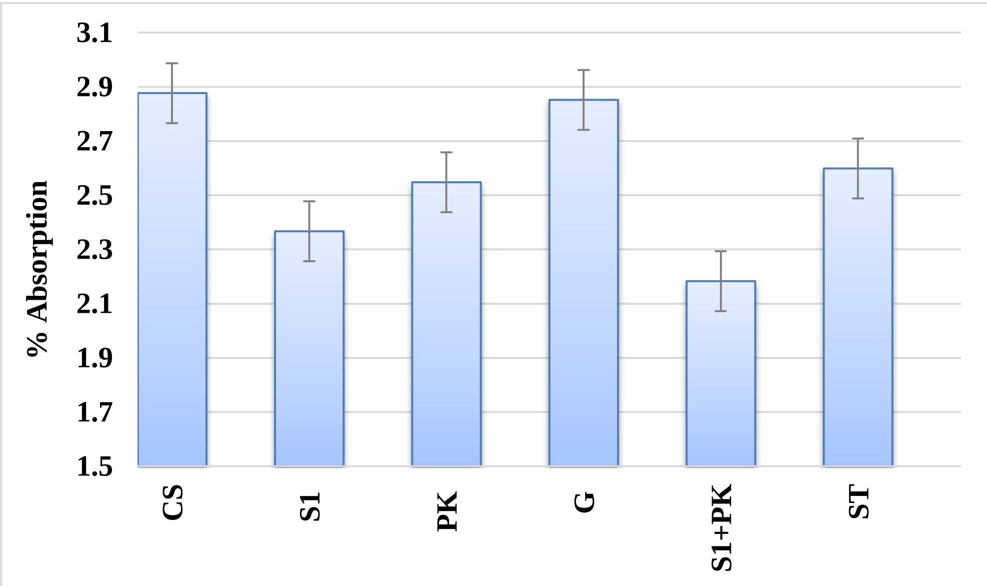


Figure 4.4: 28 Days Absorption after Immersion

4.5.1.1.3 Absorption After Immersion And Boiling

Absorption after immersion and boiling, % =$\left[\frac{C-A}{A}\right] x\ 100$]

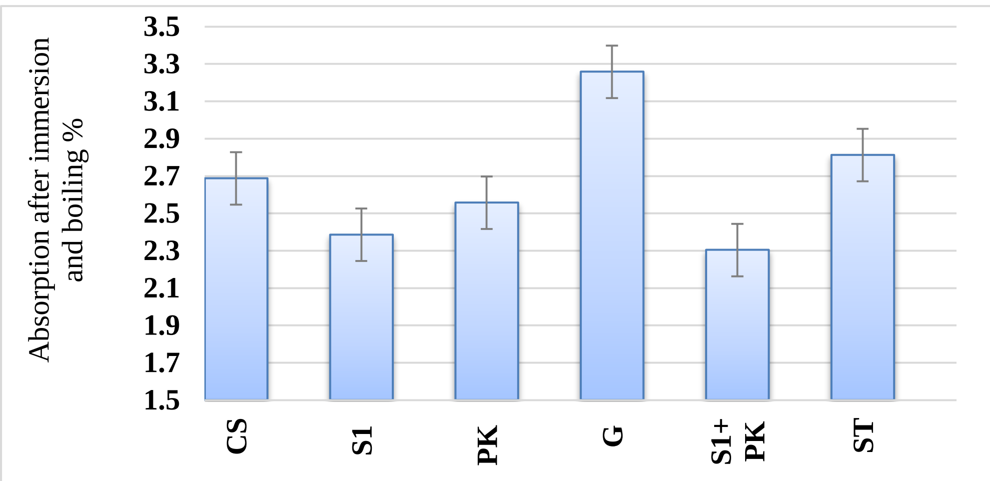


Figure 4.5: 28 Days Absorption after Immersion and Boiling

4.5.1.1.4 Bulk Density Dry

Since loss of mass in water is equal to mass of displaced water, and volume of specimen therefore mass of specimen in water after immersion and boiling is:

Apparent Mass =Mass in air after immersion and boiling – Volume

Bulk density, dry = $\left[\frac{A}{C-D}\right] x\ \rho = g_1$

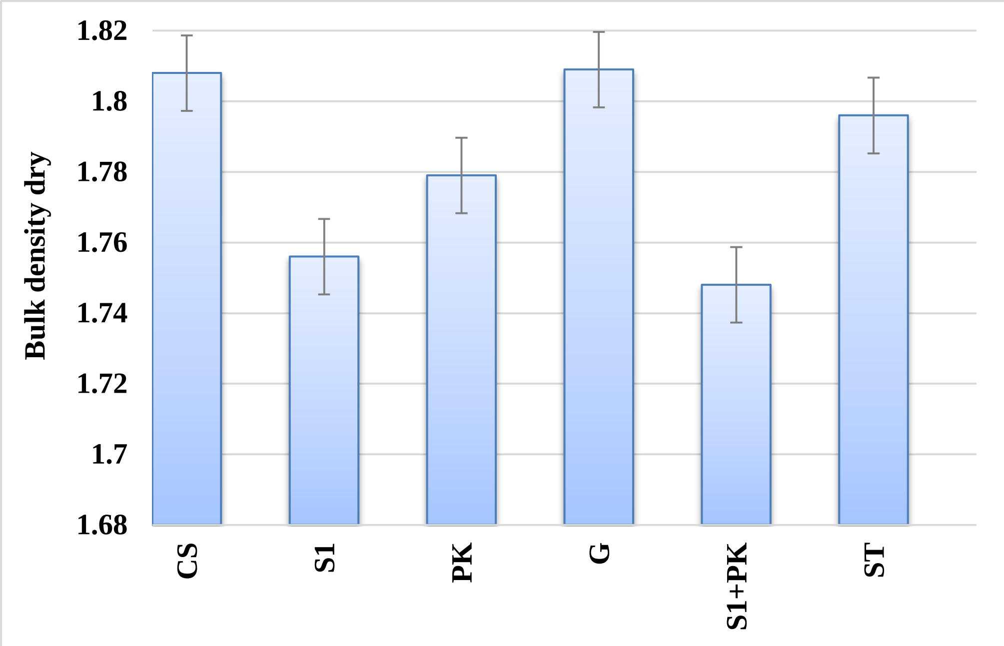


Figure 4.6: Bulk Densities Dry

4.5.1.1.5 Bulk Density After Immersion

Bulk density after immersion = $\left[\frac{B}{C-D}\right] x\ \rho$

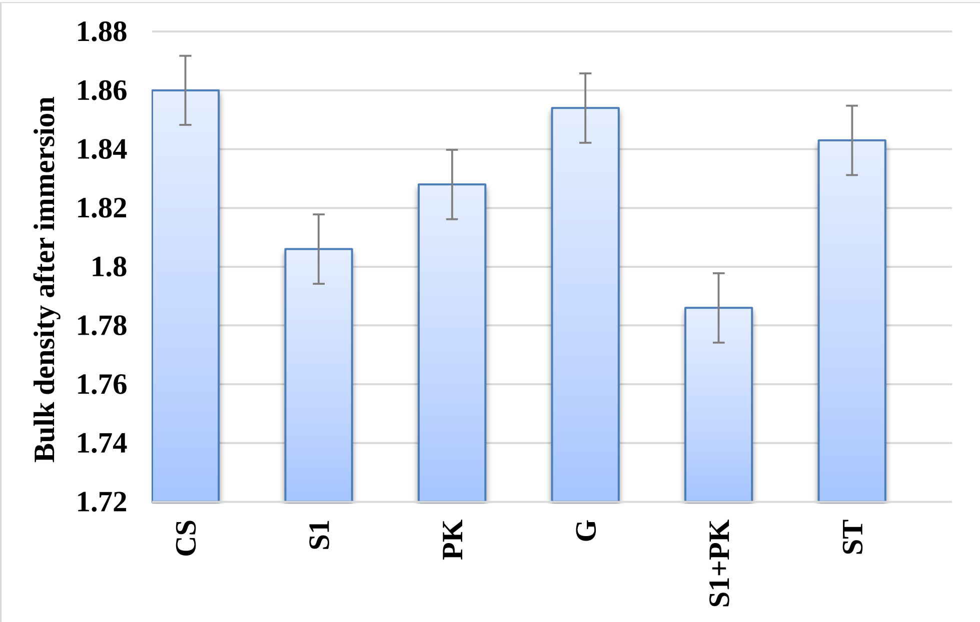


Figure 4.7: Bulk Density after Immersion

4.5.1.1.6 Bulk Density After Immersion And Boiling

Bulk density after immersion and boiling = $\left[\frac{C}{C-D}\right] x\ \rho$

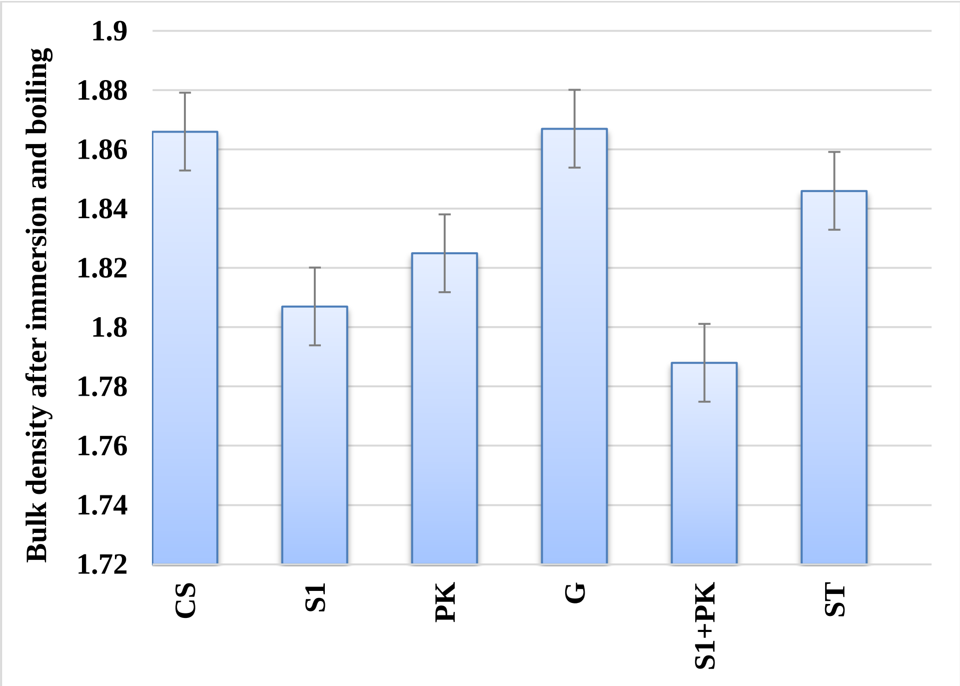


Figure 4.8: Bulk Density after Immersion and Boiling

4.5.1.1.7 Apparent Density

Apparent density = $\left[\frac{A}{A-D}\right] x\ \rho = g^2$

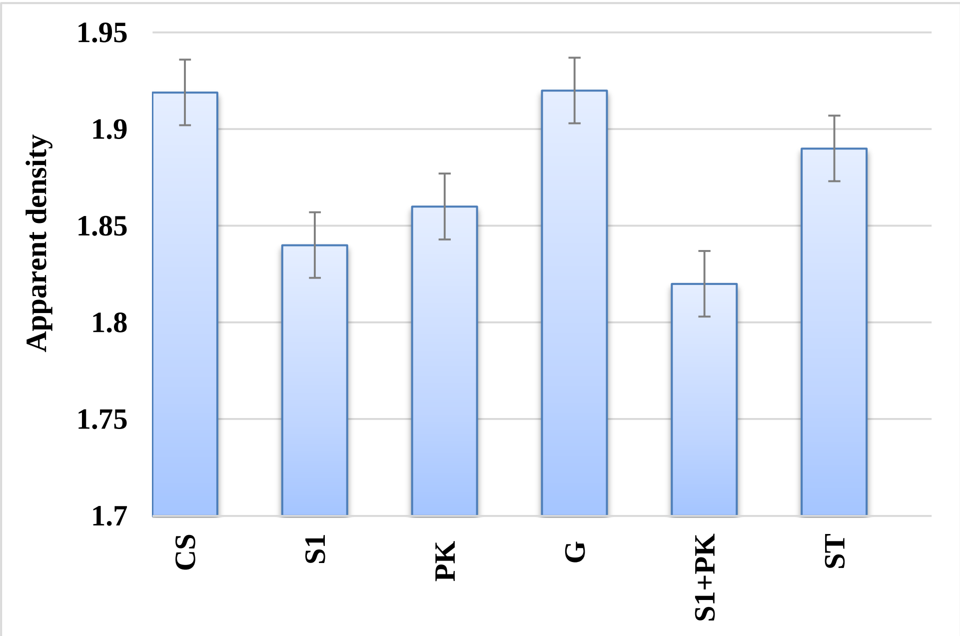


Figure 4.9: Apparent Densities

4.5.1.1.8 Volume of Permeable Pore Space (Voids)

Volume of permeable pore space (voids), % $=\left[\frac{g2-g1}{g2}\right] x\ 100]$

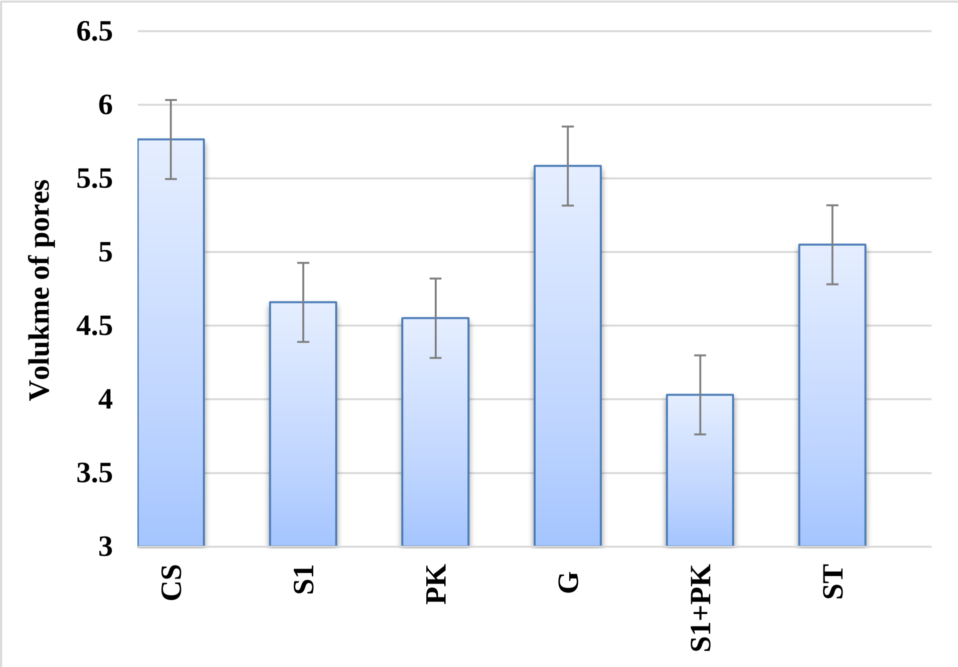


Figure 4.10:Volume of Permeable Pore Spaces (voids)

4.5.1.2 Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials (ASTM D5084-10)

After the conduction of test for the measurement of volume of permeable pore spaces we came to know that concrete samples prepared with gypsum, do not contribute towards the reduction of pores and permeability of concrete. So these concrete samples prepared with gypsum were discarded.The samples of 1:2:4 concrete of 1.5” slump with addition of gypsum, gave almost similar results as that of 1:2:4 concrete of 1.5” slump itself. Therefore no improvement in waterproofing property could be noted by us. The reason could be as explained by Mehta that pozzolanas are very slow in pore blocking in concrete. The comparison below shows its slower rate of pore blocking with time:

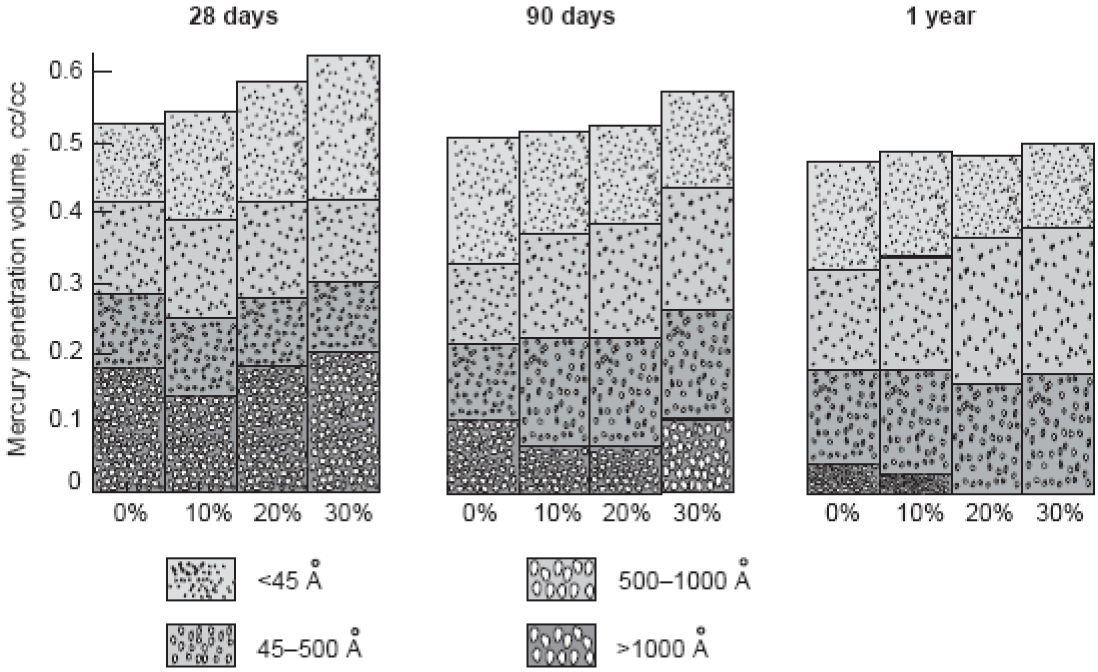


Figure 4.11: Changes in pore size distribution of cement pastes with varying pozzolan content. (Mehta, P.K., Cem. Concr. Res., Vol. 11, No. 4, Pergamon Press,New York.)

Also since the gypsum was used as partial replacement of cements therefore improvement in permeability reduction was not achieved. If gypsum is used as an additive improvement in results might be achieved.

Now for hydraulic conductivity test value of k is calculated as

$$k \text{ (cm/sec)} = \frac{a}{A} \times \frac{L}{\Delta t} \times \ln\left(\frac{h1}{h2}\right) \qquad (4.1)$$

Here

a = 1 cm^2

A = 81.073 cm^2

L = 15.24 cm

Δt = 604800 sec

h_1 =200 cm

h_2 = 200 – x

1ml = 1 cm

Where x = total head to drop from clearly marked graduations on burette

After putting values in equationwe get;

$$k\ (\text{cm/sec}) = \mathbf{3.108\ x\ 10^{-7}\ x\ \ln\left[\frac{h1}{h2}\right]}$$

Table 4.10: Hydraulic Conductivities of Samples

Samples	x (head drop)	k (cm/sec)
Controlled Samples (CS)	8	1.2687×10^{-8}
Sika -1 (S1)	6.2	0.979×10^{-8}
Sikament 512 Pk (PK)	7.3	1.156×10^{-8}
S1 + PK	4.9	0.771×10^{-8}
Surface Treatment (ST)	7.6	1.204×10^{-8}

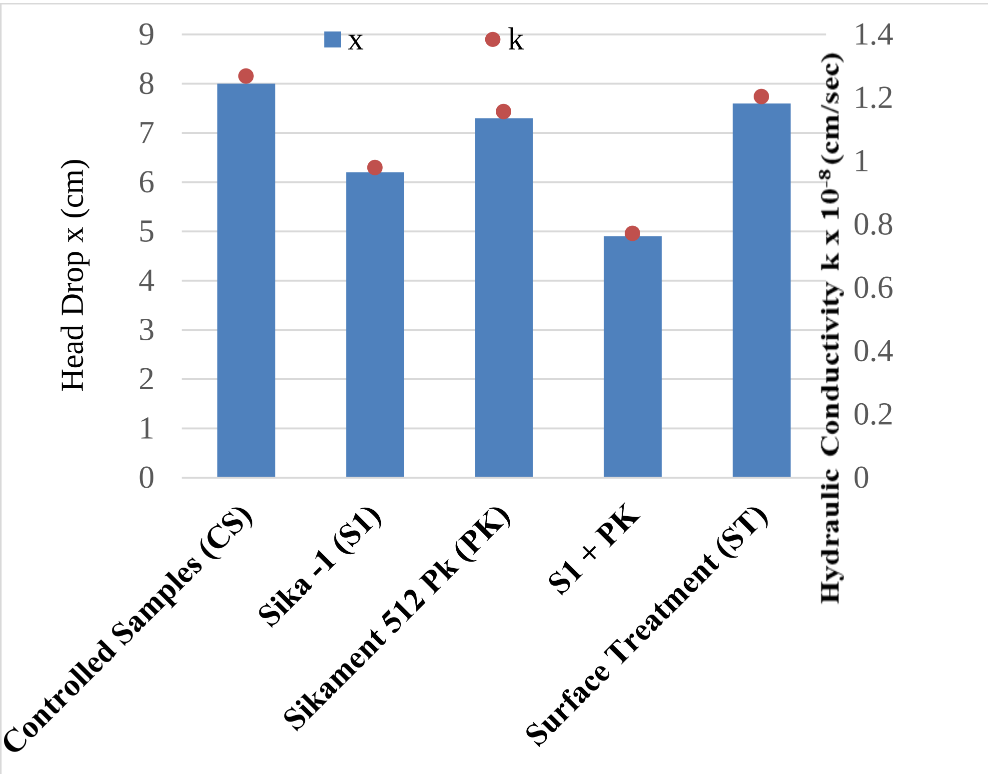


Figure 4.12: Permeability Test Results for Hydraulic Conductivity

4.6 Summary

Following the research strategy described in previous chapter, in this chapter we carry out the laboratory testing and result analysis. Laboratory testing is carried out on both hardened and fresh concrete samples. For hardened concrete, controlled samples were prepared in the form of cubes. Surface application of crystalline solution is done on hardened and cured samples. This technique blocks the capillary pores on the surface of hardened concrete. In regard of fresh concrete different admixtures are used during the casting of samples. They were formed the part of the mix. These samples then are used to carry out the water absorption test for permeability and also falling head permeability tests. In the end analysis of results of for mentioned laboratory tests gave the satisfactory and encouraging results.

CHAPTER 5
BIO-MINERIALIZATION OF BACTERIA IN CONCRETE

5.1 Introduction

Traditional products have been extensively used in the past as a water proofing material and are still in use. The drawback in these materials is however, that they are less durable in severe weather conditions and are badly affected by ultraviolet rays. They become brittle and separate out of the surface. There is therefore, a need to devise such techniques which are long lasting and pose less maintenance problems.

Cracks can occur in concrete structures due to multiple reasons such as autogenous shrinkage, freeze-thawreactions, and mechanical compressive- and tensile forces. Although micro-cracks do not necessarily resulting significant strength loss of concrete, the ingress of water and other reactive chemicals such as chloride and water may pose a threat to the steel reinforcement as these strongly enhance its corrosion rate. Thus for durability reasons and potential repair costs, crack occurrence should be minimized or, alternatively, occurring cracks should ideally be healed directly after formation by an autonomous repair mechanism. Different autonomous repair systems are feasible. One such a self-healing mechanism could involve secondary hydration reactions of still present but not fully reacted cement particles. Although a high percentage of non-reacted cement particles within its matrix may result in a concrete with a substantial self-healing capacity, the material characteristics of the initial concrete structure may not be satisfactorily as it may be more brittle and initially weaker as wanted.

Another self-healing mechanism could be based on the addition of a self-healing agent that would make up a part of the concrete matrix without or insignificantly affecting its structural and mechanical characteristics. Crack occurrence in reinforced concrete should be minimized for both durability and economic reasons as crack repair is costly. Autogenous repair, or self-healing, of concrete would save a substantial amount of money, as manual inspection and crack repair could be minimized. Thus, a reliable self-healing mechanism for concrete would not only result in more durable structures, but would also be beneficial for the global economy. The potential of different species to precipitate calcite, produce endospores, survive concrete- production, and heal cracks by sealing them with calcite is a basic mechanism involved. Alkali-resistant spore-forming bacteria embedded in the concrete matrix can precipitate substantial amounts of calcite. The bacterial approach thus seems a highly promising mechanism to mediate self-healing in concrete structures.

Bacteria naturally occur virtually everywhere on earth, not only on its surface but also deep within, e.g. in sediment and rock at a depth of more than 1 km (Jorgensen &D'Hondt 2006). Extremophilic bacteria a suitable candidate for the purpose, i.e. bacteria that love the extreme, are found in highly desiccated environments such as deserts (DeLaTorre et al 2003), but also inside rocks (Fajardo-Cavazos & Nicholson2006) and even in ultra-basic environments (Pedersen et al 2004) which can be considered homologous to the internal concrete environment. Many desiccation and alkali-resistant bacterial species has ability to form endospores. These specialized cells are characterized by an extremely low metabolic activity, are known to be able to resist high mechanically- and chemically induced stresses (Sagripanti et al 1996) and are viable for periods up to 200 years (Schlegel 1993). In some previous studies the application of bacteria for cleaning of concrete surfaces (DeGraef et al 2005) and strength improvement of cement-sand mortar (Ghosh et al 2005) had also been studied.

5.2 Bacteria

Bacteria are living things that have only one cell. Under a microscope, they look like balls, rods, or spirals. They are so small that a line of 1,000 could fit across a pencil eraser. Most bacteria won't hurt you - less than 1 percent of the different types make people sick. Many are helpful. Some bacteria help to digest food, destroy disease-causing cells, and give the body needed vitamins. Single-celled microorganisms that can exist either as independent (free-living) organisms or as parasites (dependent on another organism for life). Bacteria were among the first life forms to appear on Earth, and are present in most of its habitats. Bacteria inhabit soil, water, acidic hot springs, radioactive waste, and the deep portions of Earth's crust. Bacteria also live in symbiotic and parasitic relationships with plants and animals. There are typically 40 million bacterial cells in a gram of soil and a million bacterial cells in a millilitre of fresh water. There are approximately 5×10^{30} bacteria on Earth, forming a biomass which exceeds that of all plants and animals.

Ability of specific type of bacteria to form calcium carbonate on contact with water is greatly used in construction industry. When it is incorporated in concrete this production of calcium carbonate can act as healing agent in concrete thus making it self-healing. Through this micro cracks up to 0.3mm thickness can be healed. Bacteria which in turn will give strength to the concrete through the process of metabolically mediated calcium carbonate precipitation and also contribute to the strength and durability of the concrete. Concrete, due to its high internal pH, relative dryness and lack of nutrients needed for growth, is a rather hostile environment for common bacteria, but there are some bacteria may be able to survive in this environment and increase the strength and durability of concrete.

As it is evident that due to harsh internal conditions of concrete no simple bacteria can survive a day. In order to make concrete self-healing we have to use type of bacteria which can survive the zero life conditions of bacteria. Strains of the bacteria genus Bacillus were found to thrive in this high-alkaline environment of concrete. Such gram positive bacteria have extremely thick outer cell membrane that enables them to remain viable until a suitable environment is available to grow. They would become lively when the cracks form on concrete surface allowing water to ingress into the structure. This phenomenon will reduce the pHof the concrete environment where the bacteria incorporated become activated. Nutrients are supplied along with bacteria in suspension helps in producing calcite crystals. It is found that this bio mineralisation process will not interfere with the setting time of the concrete. The most expensive ingredient in developing bacterial concrete is nutrients. So any inexpensive alternative for laboratory growth media would potentially bring down the cost of the bacteria based self-healing sustainable concrete.

5.1.1 Suitable Bacteria for incorporation

i. Bacillus Subtilis
ii. Bacillus Cereus
iii. Bacillus Sphaericus
iv. Bacillus Pasteurii

5.1.2 Nutrients

i. Peptone based nutrients
ii. Calcium Lactate
iii. Extract yeast
iv. Broth

5.1.3 Encapsulation (LWA): An incorporation technique

In order to substantially increase functionality in time, the incorporated two-component healing agent comprising of bacteria and nutrients was protected by immobilization porous expanded clay particles.Impregnation of the light weight aggregates (LWA) occurred under vacuum, twice with acalcium lactate solution and finished with a bacterial spore suspension. LWA were dried in an oven in between impregnation treatments and before application. After completion of the impregnation treatments expanded clay particles contained 6% healing agent by weight. In order to make a concrete mixture self-healing, part of the aggregate material in the range of 2-4 mm is replaced by similarly sized healing agent containing LWA, corresponding to a healing agent content of 15 kg m^{-3}concrete. Capacity to heal cracks is substantially improved for concrete containing in LWAencapsulated healing agent.

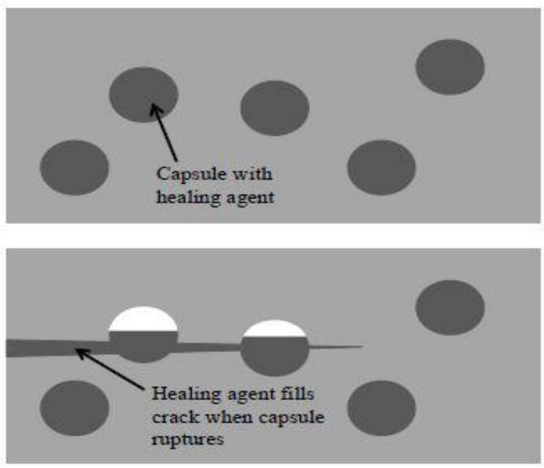


Figure 5.1: Encapsulation of Bacteria in Concrete

5.2 Basic Concept

5.2.1 Bio-mineralization

Bioengineered Self-repairing concrete biologically produces calcium carbonate crystals to seal cracks that appear on the surface of the concrete structures.

Specific spore forming alkaliphilic bacteria genus Bacillus, supplied with a calcium-based nutrient are incorporated in to the concrete suspended in mixing water. This bacteria based self-healing agent is believed to remain hibernated within the concrete for up to 200 years. When cracks appear in a concrete structure and water starts to seep in through, the spores of the bacteria starts microbial activities on contact with the water and oxygen. In the process of precipitating calcite crystals through nitrogen cycle the soluble nutrients are is converted to insoluble$CaCO_3$. The $CaCO_3$ solidifies on the cracked surface, thereby sealing it up. It mimics the process by which bone fractures in the human body are naturally healed by osteoblast cells that mineralize to reform the bone. The consumption of oxygen during the metabolic biochemical reactions to form $CaCO_3$ helps in arresting corrosion of steel because the oxygen is responsible to initiate the process of corrosion thereby increasing the durability of steel reinforced concrete structures.

5.3 Working Principle

In concrete the cracks up to 0.2 mm wide are healed autogenously. Such micro cracks are acceptable as these do not directly influence the safety and strength of the concrete. Research has shown that autogeneous healing happens due to hydration of non-reacted cement particles present in the concrete matrix when comes in contact with ingress water resulting in closure of micro cracks. However, because of the variability of autonomous crack healing of concrete micro cracks can still occur. The inbuilt bacteria-based self-healing process was found to heal cracks completely up to 0.5 mm width. On the surface of control concrete, calcium carbonate will be formed due to the reaction of CO_2 present with calcium hydroxide present in the concrete matrix according to the following reaction:

$$CO_2 + Ca\,(OH)_2 \longrightarrow CaCO_3 + H_2O$$

The calcium carbonate production in this case is due to the limited amount of CO_2 present. As $Ca\,(OH)_2$ is a soluble mineral gets dissolved in ingress water and diffuse out of the crack in the form of leaching. The self-healing process in bacteria incorporated concrete is much more efficient due to the active metabolic conversion of calcium nutrients by the bacteria present in concrete:

$$Ca\,(C_3H_5O_2)_2 + 7O_2 \longrightarrow CaCO_3 + 5CO_2 + 5H_2O$$

This process does not only produce calcium carbonate directly due to microbial metabolic process but also indirectly due to autogeneous healing. This process results in efficient bio based crack sealing technique. Bacteria can able to precipitate $CaCO_3$ in the high alkaline environment by converting urea into ammonium and carbonate. The ammonia degradation of urea locally increases the pH and promotes the microbial deposition of carbonate as calcite crystals in a calcium rich environment along with maintaining the pH of concrete. These precipitated crystals can thus seal the cracks.The microbial precipitation of calcite crystals is determined by factors such as the concentration of dissolved inorganic carbon in the form of available nutrients, the pH of the environment, availability of calcium ions and the presence of nucleation sites. The first three factors are based on the metabolic process of the bacteria species added while the last factor is based on the cell membrane of the bacteria. The bacteria used for study exhibits urease activity which catalyses the hydrolysis of urea ($CO(NH_2)_2$) into ammonium (NH_4^+) and carbomate (CO_3^{2-}). First, urea is hydrolysed to carbonate and ammonia. Carbomate then hydrolyses to form additionally ammonia and carbonic acid. These products subsequently form bicarbonate and ammonium and hydroxide ions. The ammonia is responsible for pH increase, which in turn shifts the bicarbonate equilibrium, resulting in the formation of calcium carbonate ions. Since the cell membrane of the bacteria is negatively charged, the bacteria draw cations from the environment, including Ca^{2+}, to deposit on their cell surface. The Ca^{2+} ions subsequently react with the CO_3^{2-} ions, leading to the precipitation of $CaCO_3$ at the cell surface that serves as a nucleation site.

$$Ca^{2+} + Cell \rightarrow Cell\text{-}\ Ca^{2+} \quad Cell\text{-}\ Ca^{2+} + CO_3^{2-} \rightarrow Cell\text{-}\ CaCO_3$$

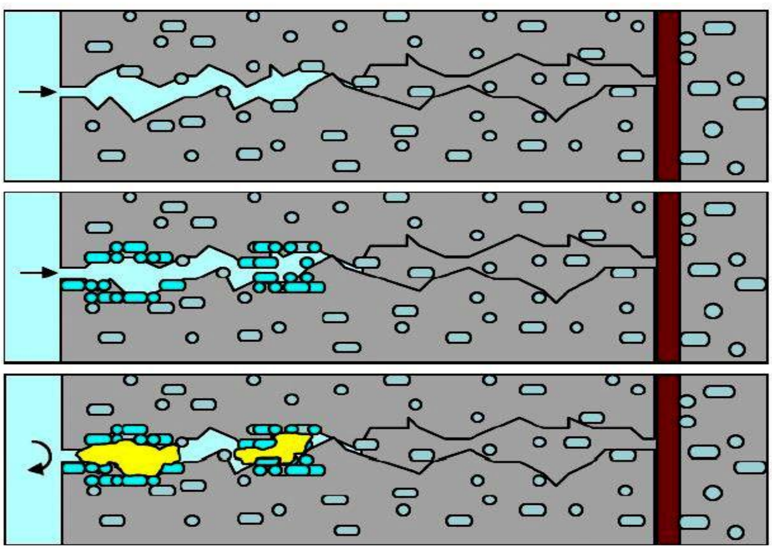


Figure 5.2: Mechanism of Bacterial Healing

5.4 Reduction in Permeability

Permeability of concrete is important characteristic of concrete that affects its durability. Concrete with low permeability has been reported to last longer (Nolan et al., 1995). Permeation is required for controlling the ingress of moisture, ionic and gaseous species into the concrete. Once they get into concrete structure, the structure no longer maintains its structural integrity; the lifespan is reduced, and the general safety of the public is severely in danger. Conventional techniques like application of chemical admixtures like plasticizers, water reducing agent are known which improve the workability of concrete by reducing intergranular friction finally affecting porosity. The bio deposition by microbial concrete should be regarded as a coating system. This is because of the fact that precipitation is mainly on the surface due to limited penetration of bacteria in the porous matrix. Ramakrishna et al (1998) reported an increase in resistance of concrete towards alkali, freeze thaw attack, drying shrinkage and reduction in permeability upon application of bacterial cells. De Muynck et al (2008) studied the effect of bio deposition of calcite on permeability characteristics of mortar. The presence of biomass contributed to a large extent in the overall decrease of the permeability. Bacterial treated concrete have better resistance towards chloride penetration as compared to untreated concrete. The increased resistance towards the migration of chlorides of concrete treated with bio deposition was similar to that of the acrylic coating and the water repellent silanes and silicones and larger than in the case of the silanes mixture, which were all reported to be effective in decreasing the rate of reinforcement corrosion (Basheer et al 1997; Ibrahim et al 1997). The lower permeability of the bio remediated concrete compared with that of the control concrete is probably due to a denser interfacial zone formed because of calcite precipitation between the aggregate and the concrete matrix.

5.5 Stiffness and Strength of Bio-Concrete

A correlation exists between $CaCO_3$ content, dry weight and strength. The strength obtained depends on the dry sand density, as densely packed sand requires less bio cementation as compared to less dense sand to achieve the same strength (Van Paassen et al. 2009) and the point-to-point contact of $CaCO_3$ crystal which bridges between two adjacent granules (Al-Thawadi 2008). The maximum unconfined compressive strength (UCS) achieved at small scale was up to 30MPa by Al-Thawadi (2008). The strength mildly i. increases with strength of the individual particles and ii. Decreases with particle size, particle pre-coating with $CaCO_3$ and roundness of particles (Al-Thawadi 2008). Additionally, reactions that take place very quickly form soft and powder like crystals, while naturally limestone form slowly and are very hard crystals (Whiffin 2004). Homogenous development of strength is influenced by the distribution of bacteria or urease activity as the bacteria are either absorbed, strained or detached during the flow andtransportation through the granules (Van Paassen et al. 2009). Few factors affecting this are i. Cell wall characteristics like hydrophobicity, charge and appendages and iii. Solid properties like grain size distribution, surface texture and mineralogy (Al-Thawadi 2008). Regarding stiffness of bio concrete, it follows a similar trend as strength (Van Paassen et al. 2009).

5.6 Self-healing materials in view of Environmental Stewardship

According to Long (2000) the infrastructure in industrialized countries accounts for at least 50% of our national wealth. From that he inferred that the performance and quality of our infrastructure are of fundamental importance to urban sustainability and the well-being of our environment. Extending the service life of our infrastructure will certainly contribute to mitigation of the ecological footprint. We should be aware of this when designing infrastructural works and when making choices for concrete mixtures. The development and use of self-healing materials are most challenging options to accomplish the need for durable infrastructure. In view of the large impact of the building industry on the environment, promoting self-healing materials can be considered as a matter of environmental stewardship. Since concrete is, volume wise, the most often used building material, enormous savings are achievable, even if we make small improvements in the quality and durability of our infrastructure. On top of that it is worthwhile to know that investing in self-healing materials in view of reduction of maintenance costs finally pays off.

5.7 Laboratory Trial for Biologically Engineered Concrete

Laboratory trial for Biologically Engineered Concrete is conducted in COMSATS with the collaboration of Ayub Medical College and COMSATS Institute of Information Technology, Abbottabad. Bacteria is acquired from biotechnology laboratory of Ayub Medical College. Although bacteria acquired is not the one specified for the purpose but to conduct the initial trial it is being used. Following steps are followed for this purpose:

i. Casting of concrete is conducted at the concrete laboratory of COMSATS.
ii. Cylinder is casted with the incorporation of bacteria using normal size aggregate and fine sand.
iii. No other admixture or plasticizer is used to make concrete better. Bacteria is added in suspension state.
iv. Bacteria is first mixed in mixing water then this water is used to cast a concrete sample. Normally it takes a week to form calcium carbonate precipitation with in the concrete sample during the continuous process of curing.
v. After curing for 7 days sample is put under compression test to assess its compression strength and then to use fractured sample for the detection of bacteria.
vi. Process for the detection of bacteria is carried out at the Ayub Medical College. Results have shown that no bacteria survived the harsh conditions of concrete.
vii. It proves the fact that only specified bacteria which can survive the life extent extreme conditions of concrete is to be used to form Biologically Engineered Concrete. No other type of bacteria can serve the purpose. This finding will put foundation for the future laboratory trials of bacterial concrete.
viii. Presently work is being carried out on Biologically Engineered Concrete in NUST, H-12 Campus and their results are yet to be revealed.

5.8 Summary

Biologically Engineered Concrete is modern technique to control permeability of concrete without addition of any admixture or plasticizer. Only bacteria is suffice to fill the internals pores of concrete making it almost impermeable. Life of this concrete is approximately estimated to be 200 years. Normal concrete hardly exist up-to 50 years. Calcium Carbonate as bi-product not only fills the pores but also increase the durability of concrete by increasing structural strength. It is environmental friendly and cost efficient technique. Its initial cost is high which broadly covers the cost of bacteria and its nutrients and it is one time cost as no maintenance needed due its self-healing action. This high initial cost is less than the cost of maintenance of controlled concrete over its life cycle. Performance curves for the period of maintenance, for controlled concrete and bacterial concrete has shown us that bacterial concrete is cost effective over the life cycle. Controlled concrete need maintenance after intervals till complete failure, while bacterial concrete being self-healing repairs the cracks automatically, restoring the little less state then original.

CHAPTER 6
FIELD APPLICATION

6.1 Introduction

Until now we have studied small scale laboratory application of admixtures and water-reducers which are conventionally used. Different concrete specimens are casted using different proportions of chemicals separately. Laboratory tests have shown satisfactory results, according to the results these chemicals are efficient enough to reduce the permeability of concrete to a rational level. Besides laboratory testing of these chemicals they have different applications in field according to the type of structure. This has laid the base for examining these chemicals in field conditions. As it is evident that small scale conditions can not verify efficiency of these chemicals in field. Field conditions are far more different then laboratory conditions. To give strong base to our study we carried out field testing on different structural conditions.

In field environment we come across different types of structures. Every single structures behave differently in same and different conditions (Nolan et al., 1995). We have segmented these structures according to their physical conditions on site naming:

i. Existing structures: which are already built and have passed definable part of their structural life and are affected by seepage problem

ii. Newly built structures which are treated while they are in construction phase. In former existing concrete is treated and hence cold joint problem is also addressed, while in later fresh concrete is treated with chemical to prevent expected seepage problem.

iii. A cold joint is an undesirable discontinuity between layers of concrete that occurs when one layer of concrete is allowed to harden before the rest of the concrete is poured in what is meant to be a single, solid mass. The discontinuity occurs between the layers due to the inability of the freshly poured, wet concrete to intermix with and bind properly to the hardened concrete (Neville A.M 1963).

Problems associated with cold joints range from the relatively minor to the very serious. At the less serious end of the spectrum, a cold joint may result in a visually unappealing discontinuity that is visible on the surface once the concrete has hardened (Schmidt P 2008). This kind of aesthetic defect may simply be concealed rather than repaired. A more serious problem associated with a cold joint is the possibility of moisture intrusion into the concrete section. If water settles in the joint, it may lead to degradation of the concrete under certain environmental conditions (Arnold R. 2003). For example, as water expands when it freezes and then contracts when it melts, water trapped in a cold joint may cause cracking or erosion of the material. Moisture may also damage other things beyond the concrete mass if it is able to seep all the way through it. So specific chemical is there for the cold joint problem which can make it seal against water.

Fresh concrete is the state of concrete in which concrete is in its plastic state or it will not be wrong to call fresh concrete as liquid concrete (Neville A. M. 1963). Fresh concrete is initial stage of concrete, if concrete is treated well in this stage it can eliminate 90% chances of seepage problem. This also includes the careful pouring of concrete that there should be no segregation of concrete. Fresh concrete comparatively to hardened concrete is easier to treat and have more chances of success. Hardened concrete is treated either through surface application of several layers of chemically treated mortar or small thickness of zero crush concrete. On the other hand fresh concrete is treated by adding calculated amount of chemical as a part of mixing water. This reduces the amount of mixing water to be used and hence we call it water-reducer (Koren et al 2012). It make concrete workable with less water. When there is less water in concrete to evaporate it will leave less pores as a result we get concrete with decreased permeability.

6.2 Testing Sites

In order to test the field potential of chosen chemicals we have carefully selected the sites within the MCE premises. MCE consist of many old built buildings which show the prominent signs of seepage due to visible foul surfaces. We selected three buildings on the basis of different seepage conditions and places. Three places are specified to treat in each building naming:

i. Roof slab in addition with cold joint
ii. Brick Masonry plastered wall and
iii. Freshly poured concrete roof slab

Following buildings are selected as sites:

i. MCE Events Hall
ii. MCE Mosque
iii. MCE gate Guard Room

These sites are selected after careful inspection and are eligible to be treated for seepage. Another characteristic of these sites is that they are hub of regular use, this will help us relate our results with sites like public assemblies. All three buildings are open to rainfall. No protection in the form of tree or large building beside them are preventing rainfall on them. This gives us the opportunity to put our treatment to test in rainfall as a source of water to see seepage control. No outer source is needed to check seepage.

6.3 Site No. 1: MCE Events Hall

MCE Events Hall is a public assembly and single story building. It is utilized for large gatherings and have the capacity of accommodating more than 150 persons with movable chairs it is rectangular building covering an area of $1500ft^2$. It consist of gable roof top made up of aluminium sheets. Veranda consist of concrete roof slab which is 3.5 feet below the gable roof elevation.

Figure 6.1: MCE Events Hall

Presence of gable roof top is source of water, which is affecting roof slab of veranda. When water strikes the gable roof, due to its shape and aluminium sheets water does not stay there rather immediately starts travelling down through roof to the veranda top. Concrete of veranda roof not only bears its share of water rather also water of gable roof. Due to high slope of gable roof water coming down strikes the concrete with more speed. Other than this, water falls on specific area continuously causing ponding, unless the rain stops. This is sure cause of making concrete permeable when it is under swear attack of water.

6.3.1 Subject Seepage Place

This building comes under the segment of treatment of concrete in hardened state in existing structure. The roof is effected with seepage above the entrance of veranda. Main place is the joint of concrete slab with the plastered wall. Seepage effected area spreads from 1m to 2m. Signs of seeped water can be seen on veranda wall in the form of chipping off of plaster and clear wetness. This place is sure to make progressive seepage if not treated well. As the joint is already affected by water and it will not be difficult for water to widen its passage through joint. Moreover it is observed that water tank on the roof of veranda is prime source of ponding on the roof. Our aim is to treat the vertex made by concrete slab and wall which is a weaker section for crack to occur. As roof slab consist of old concrete and new treatment will raise the cold joint problem. So we also catered for cold joint along the treatment

Figure 6.2: Water Tank on Event's Hall Roof

6.3.2 Chemical used

Sika-1 as 1 litre/Bag of cement

6.3.3 Treatment process

Following treatment process is used:

i. All surfaces are 100% roughened by hacking and then wire brushed and thoroughly washed down.
ii. Immediately prior to application, the surface is soaked with clean water, however, there should be no standing water or puddles present.
iii. Initially grout of Sika-1 mortar as for bonding coat is applied. It is of sloppy, brush able consistency and is vigorously applied and laid in strips. It should not be walked on before applying the bond coat.
iv. Dilute one part Sika-1 with 10 parts clean water
v. First coat of Sika-1 mortar (cement: sand = 1:1) is applied as 6 mm thick, taking care to cover the surface completely. Mix to a sloppy consistency and casted vigorously.
vi. The second coat is prepared as (cement: sand = 1:1.5) with Sika-1. Its thickness is also 6 mm. It is applies as soon as the first coat has stiffened sufficiently (after 4 hrs.). On completion, a splatter coat of the same mortar is applied and mixed to a sloppy consistency, over the whole surface to form a key for the third coat.
vii. On second day, third coat of Sika-1 mortar (cement: sand = 1:1.5) of 6 mm thickness is applied. This final coat is finished with a wood float.

Figure 6.3: Subject Seepage Place and its treatment

6.3.4 Results

Encouraging results are obtained as a result of treatment. Treatment is put under test conditions of rainfall. No sign of seepage is found at the treated place after series of rainfall sessions. In order to carefully observe the seepage the affected area is cleaned properly. Signs of old seepage are removed properly, in case if seepage occurs again we can witness it. This led us to our first success in field testing.

6.3.5 Public Witnesses (Verification of results)

As there is no instrument or method available with us to verify seepage control through calculations so after successful treatment, public witnesses are asked about the seepage control. Positive opinions are given by them. Witnesses include the people working around MCE Events Hall who are the regular witness of the subject site.

6.4 Site No. 2: MCE Mosque

MCE Mosque is single story building.It is rectangular in shape covering an area of 2030ft^2. Mosque was constructed in 1984. It consist of multiple arches combined together to form a roof top. There is a conduit between every two adjacent arches for the flow of water away from the roof. This water has only one side to drop which is on the back side of mosque. Because the slope of roof is given on the back side of mosque which is a free end and most suitable place for water to flow out of the structure.

Figure 6.4; MCE main Mosque

In order to prevent free fall off water from roof there is a drainage vessel system all along the back side of mosque at the ceiling height. All the water from roof flow on this drainage vessel. Drainage vessel then transport this water away from structure utilizing both sides of the mosques. Drainage vessel is present right above the back wall of mosque. It forms the part of roof slab. We can say that drainage vessel is present just at the start of roof at ceiling height level below arches. This vessel also forms the vertex between concrete and brick masonry wall. Vertex presents the weaker section for crack to occur. While this joint of two different materials is favourite place for crack to occur.

6.4.1 Subject Seepage Place

This building comes under the segment of brick masonry plastered wall. However there is a long strip of concrete small in width forming the part of drainage vessel. Due to this concrete strip of which vertex is part where joint is present, now crack is cause of seepage in the back wall of mosque. When water runs over the drainage vessel its seeps through crack and cause seepage in wall. Wall being of bricks catch more seepage due to capillary action of bricks. Seepage signs can be clearly seen on the outer side of wall and also inside the mosque on the same wall. Chipping off of plaster on both sides of wall louds the presence of seepage. Here cold joint problem occurs due to presence of old concrete, so it is also catered for.

6.4.2 Chemical used

There are two chemicals used at this site:

i. Sika-1 as 1 liter/Bag of cement for water proofing.
ii. Sika Latex, high performance water resistant bonding agent and mortar improver.

6.4.3 Treatment process

Following treatment process is used:

i. All surfaces are 100% roughened by hacking and then wire brushed and thoroughly washed down.
ii. Immediately prior to application, the surface is soaked with clean water, however, there should be no standing water or puddles present.

iii. Initially grout of sika latex mortar as for bonding coat is applied. It is of sloppy, brush able consistency and is vigorously applied and laid in strips. It should not be walked on before applying the bond coat.

iv. Other steps are same as for site 1.

6.4.4 Results

Satisfactory results are obtained after the treatment of the wall, but due to the age factor of the structure wall is well porous and in extreme rainfall it may show some signs of seepage.

6.5 Site No. 3: MCE gate Guard Room

MCE gate Guard Room is a single story newly built building. It consists of a two rooms with covered veranda in front. It does not have particular shape, corners on three sides and completely round on one side. It covers an area of……….. It is a brick masonry structure with 6" concrete roof slab. The particular building is all time occupied place. It is an open building with no tree or any other building obstructing rainfall and direct sun. Whole building has the same level and height. Roof slab is flashed with walls i-e no weaker section for crack to travel is provided.

Figure 6.5: MCE gate Guard Room

All around the building plinth protection of lean concrete has been provided to flow away the water from seeping to foundations. It has been plastered by rich mortar of ratio 1:2 from outside and mortar of ratio 1:3 has been used to plaster inside of the building. Veranda consist of two columns which are made of brick masonry. Roof slab is provided with a good slope to drain away the surplus water.

6.5.1 Subject Seepage Place

This building is segmented under the treatment of freshly poured concrete. So there is no seepage place as buildings is still under construction. At this site our field testing become more of prevention measure. Our chemicals will be tested on long term results to protect roof slab from seepage. We aim to reduce quantity of water used to make concrete for roof slab. With less water it is more workable by using admixture. As mentioned above roof slab is flashed with walls, so it is ensured that no honeycombing appears. All the building is of brick masonry so if there will be a little sign of seepage it will promote it. The key to success of all water proofing methods lies in making the structural elements of a building itself as water tight as possible. The current practice of using 1:2:4 concrete in more than 95 % of the roof slabs in our country should be discontinued at least in the government works as water can readily travel through the concrete body, once the overlaid water proofing layer fails. "Mix design concrete with 66% aggregate by volume shows 38% lesser shrinkage than 1:2:4 concrete with 57% aggregate by volume (Neville).

6.5.2 Chemical used

Sika-1 as 1 liter/Bag of cement for water proofing.

Figure 6.6: Addition of Sika-1 in Concrete Mix during Casting

6.5.3 Treatment process

Sika -1 is mixed in water and added to the mix during mixing. Roof is casted with nominal mix design of 1:2:4 mix, with W/C of 0.48. A total of 50 litter sika -1 is added.

Figure 6.7: MCE gate Guard Room Treatment

6.5.4 Results

Building is still in construction phase. Results can better be obtained when it comes under the men use and subjected to rain. So there are no as such results are obtained for the subject site.

6.5.5 Insitue Samples

In order to ensure good quality control and to assess the permeability of control casted under actual field conditions, few samples are casted during roof casting. Samples are properly cured according to ASTM C39 for 28 days and tested for compressive, flexural, adsorption and permeability.

Table 6.1: 28 Days Compressive Strength Results of Insitue Samples (Average Values)

Sample	28 Days Compressive Strength f'c (psi)		Flexural Strength $f_b = \frac{PL}{bd^2}$ (N/mm)	Head Drop x (cm)	Hydraulic Conductivity k (cm/sec)
	Cylinders	Cubes	Prisms	4'' Dia Cylinders	
F (Insitue Samples)	3500	4080	1.9	6	0.947×10^{-8}

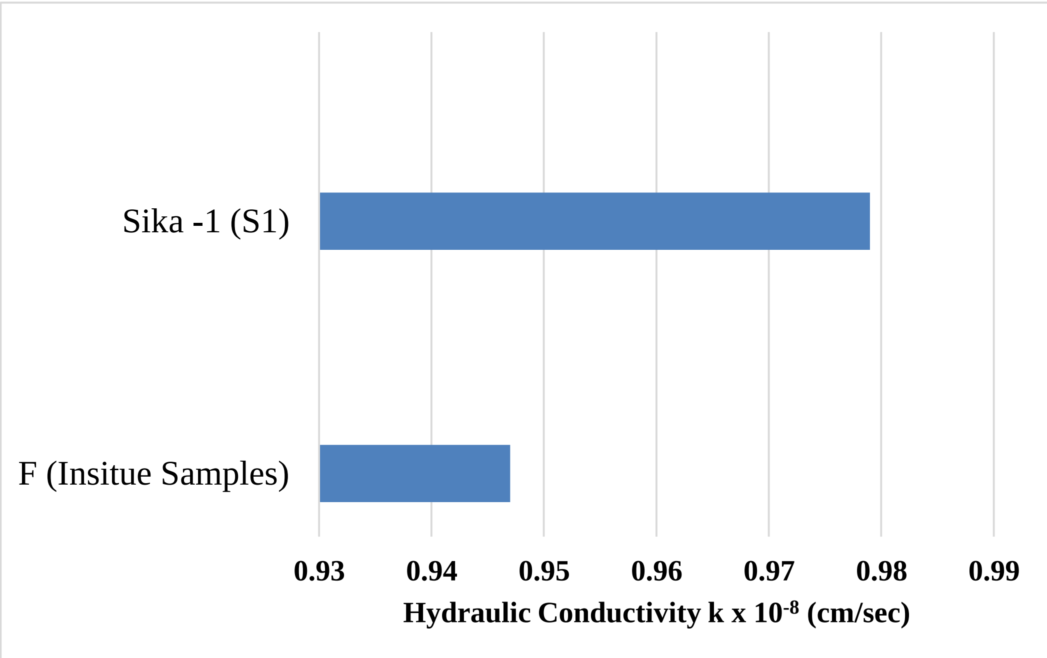


Figure 6.8: Comparison of Insitue and Lab Samples

6.6 Summary

After the successful results of laboratory testing this encouraged us to apply our permeability reduction techniques in practical field conditions. Our aim to do this is to ensure that our techniques are equally good and viable to be used in practical applications. For this purpose field are selected with in the premises of MCE. Three sites naming MCE Events Hall, MCE main Mosque and MCE gate Guard Room. MCE Events Hall and MCE main Mosque are under the heading of existing structures and MCE gate Guard Room is under newly built structures. Treatment of existing structures include the addressing of cold joint and treatment applied on the subject seepage place mention in the structure. In newly built structures admixture is formed the part of newly poured roof slab mix. This is the treatment which is applied during mixing of fresh concrete. Aim of choosing three different field conditions is to test the liability of our treatment under different circumstances.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary

Permeability of concrete is the problem associated with concrete since its invention. Approach to cater for this problem is not straight forward. Whichever techniques one uses to reduce the permeability of concrete, it cannot be completed eliminated. However it can be brought up to the expectable level. Our research followed the same course. Different techniques used on hardened and fresh concrete in the form of surface application and admixtures forming the part of the fresh concrete mix have put us wise. Though as mentioned earlier it cannot be eliminated completely, following the same course significant results have been achieved. It was ensured that the quality of material and work should meet the research requirements. Tested material was used and material which failed to satisfy the requirements was discarded. While preparation of samples it was ensured that no such practice be observed which lead to harm the integrity of concrete. It has been ensured that besides using the different techniques, no technique should effect the strength and durability of concrete. Though it was tried that applied treatments should also enhance the quality of concrete in every aspect. Challenging part of laboratory testing of the prepared samples have been performed under supervision of laboratory staff. Water absorption test and falling head permeability test were conducted according to the ASTM standards. Laboratory test gave encouraging results which lead to putting of waterproofing techniques under field conditions. Field testing was conducted with in the MCE to ensure supervision of work without hindrance. By the Grace of Almighty ALLAH field testing also turned up to be successful approach. Cold joint problem and existing concrete in field conditions were addressed. During field testing initial curing of concrete was specially done three times a day. This helped in reducing shrinkage cracks. Apart from these techniques which are required over the period of time, new technique called Biologically Engineered Concrete was also introduced. In this modified concrete bacteria is incorporated with suitable nutrients collectively forming a healing agent which makes concrete self-healing. This repairs the micro cracks appeared on the surface of concrete automatically without any external source applied. Due to its time consuming process it has been limited to only one laboratory trial. However this is modern technique and it is hoped that in coming time it will be possible for future engineers to study this technique extensively.

7.2 Conclusions

The objective of this research project was to assess the permeability of concrete.The effectiveness of various samples tested for waterproofing is discussed below:

a. The untreated sample of 1:2:4 concrete with 1.5” slump absorbed the max quantity of water (2.9 %) as evident from the graph shown. Whereas a similar sample of 1:2:4 surface treated concrete absorbed comparatively less water (2.6%) but still on higher side compared to the other samples. It means if by some mechanism we block the capillary pores of concrete, it will result in reduction in permeability.
b. The samples of 1:2:4 concrete of 2.5” slump with water reducing agent (Sikament 512PK) shows considerable reduction in water adsorption (2.5%) as evident from graph. It means that reducing the mixing water even in 1:2:4 concrete preferable results can be achieved. Since there is no concept of a measured quantity of water in 1:2:4 concrete therefore at site the worker may add any quantity of water at will and will therefore produce inferior quality of concrete from permeability point of view.
c. The samples of concrete using Sika-1 as water proofer showed excellent results by allowing less quantity of water to seep through. Since this will become an integral part of concrete, it is expected to remain there for indefinite time.
d. Combination of sika-1 andsikament 512PK proved to be most effective in permeability test with the least hydraulic conductivity (k). Sample of Sika-1 produced the second best result, followed by sikament 512PK, proving that they were more effective than surface treatment.
e. The lower is water content, the lesser will be excess water to evaporate to result in lesser interconnected capillary pores.
f. On the basis of lab experiments and results it is concluded that no treatment can make concrete completely impermeable. But with the use of proper

combination permeability of concrete can be reduced to a significant level. However, it is observed that giving proper gradient to avoid ponding is also very effective to avoid seepage.

g. For the best results, use the combination of Sika1 and 512PK for reducing permeability. Application of Sika latex (adhesive) is recommended to avoid cold joint.

h. Roofs must have sufficient slope for ready flow of water and for large buildings a roof plan must be prepared in advance to facilitate working at the construction stage. The number and size of outlets must be adequate to cater for blockage of any outlet.

7.3 Recommendations

a. There is a need to use properly designed concrete mixes with formulation for water tightness in roofs and other structural elements likely to be affected by water. This will not only help in controlling seepage but will also enhance durability of concrete and the building as a whole. The conventional concrete mixes (e.g. 1:2:4 concrete) should not be made with excess water content as it enhances permeability of concrete. The reduced quantity of water content helps in the following ways.

b. There is a tendency amongst the site workers to leave behind the waste cement mortar on top of roof which will block easy flow of water. The roof tops must be checked for removal of all waste material and periodically cleaned.

c. The practice of placing water tanks directly on roof slabs must be discontinued as is being done commonly in the cantonment and elsewhere. The water tanks when full with water will overload the slab portion and cause excessive deflection. The rain or overflowing water will pond on and will become a major source of leakage through roofs and walls. The spoiling of walls and spalling of concrete cover is a common phenomenon which can be witnessed commonly. If there is no alternative but to place a water tank on a roof top then it should be done on a specially prepared and sufficiently raised slab. A waterproofed trough should preferably be formed beneath the water tank in the roof slab portion around the tank so that any water leaking or overflowing must be channelized away from the building without any damage. Water pipe must not be in contact with the concrete as itvibrateswhen water flows through it resulting in minor cracks, making it more vulnerable to seepage.

d. Besides admixtures used in this research study there are numerous other admixtures/chemicals available which can be adopted according to local weather conditions, as every structural element has its own exclusive need.

e. Sheets, membranes, synthetic polymers, epoxyetc, may also provide useful solutions for waterproofing system, this area should to be explored.

f. As biological engineered concrete is relatively a new dimension, there is one key obstacle that needs to be overcome if self-healing concrete is to transform concrete construction in the next decade. The issue is that the clay pellets holding the self-healing agent comprise 20% of the volume of the concrete. That 20% would normally comprise harder aggregate such as gravel. The clay is much weaker than normal aggregate and this weakens the concrete by 25% and significantly reduces its compressive strength. In many structures this would not be a problem but in specialized applications where higher compressive strength is needed, such as in high-rise buildings, it will not be viable.

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APPENDIX

APPENDIX A-Calculations of ASTM C642 – 13 Standard Test Method for Density, Absorption, and Voids in Hardened Concrete

Table 0.1: Absorption after immersion

Sample	**Cylinders (4" Dia)**			
	A	**B**	**Absorption after immersion %** $\frac{B-A}{A}$ x 100	**Average**
CS-a	2153.6	2215.1	2.85568	2.877
CS - b	2227.5	2292.1	2.90011	
S1 - a	2219.6	2271.3	2.32924	2.367
S1 - b	2228.1	2281.7	2.40563	
PK - a	2226.6	2282.6	2.51504	2.548
PK - b	2292.1	2361.7	2.58278	
G - a	2224.6	2288.2	2.83092	2.852
G - b	2295	2361	2.87582	
S1+PK-a	2224.7	2272.7	2.15759	2.183
S1+PK-b	2295.1	2345.8	2.20905	
ST-a	2153.6	2210	2.61887	2.599
ST-b	2227.5	2285	2.58136	

Table 0.2: Absorption after immersion and Boiling

Sample	Cylinders (4" Dia)			
	A **(**mass of oven-dried**) gm**	**C** (mass of surface-dry sample in air after immersion andboiling) **gm**	**Absorption After Immersion And Boiling%** $\frac{C-A}{A}$] x 100	**Average**
CS-a	2153.6	2220.7	3.11571	2.687
CS - b	2227.5	2300.1	3.25926	
S1 - a	2219.6	2271.3	2.32924	2.385
S1 - b	2228.1	2282.5	2.44154	
PK - a	2226.6	2282.6	2.51504	2.557
PK - b	2292.1	2351.7	2.60023	
G – a	2224.6	2297.5	3.27699	3.258
G – b	2295	2369.4	3.24183	
S1+PK-a	2224.7	2275.6	2.28794	2.304
S1+PK-b	2295.1	2348.4	2.32233	
ST-a	2153.6	2214.3	2.81854	2.812
ST-b	2227.5	2290	2.80584	

Table 0.3: Bulk Densities Dry

Sample	Cylinders (4" Dia)				
	A **(**mass of oven-dried**)** **gm**	**C** (mass of surface-dry sample in air after immersion andboiling) **gm**	**D** apparent mass of sample in water **gm**	**Bulk Density Dry** [$\frac{A}{C-D}$] x ρ = $g_{1,}$ (ρ = 1 mg/m^3 = 1 g/cm^3) **mg/m^3**	**Average**
CS-a	2153.6	2220.7	1034.6	1.81570	1.808
CS - b	2227.5	2300.1	1064	1.80204	
S1 - a	2219.6	2271.3	1022	1.76000	1.756
S2 - b	2228.1	2282.5	1011.7	1.75331	
PK - a	2226.6	2282.6	1025.3	1.77094	1.779
PK - b	2292.1	2351.7	1070	1.78832	
G - a	2224.6	2297.5	1059	1.79621	1.809
G - b	2295	2369.4	1109.8	1.82200	
S1+PK-a	2224.7	2275.6	1000	1.74404	1.748
S1+PK-b	2295.1	2348.4	1039	1.75279	
ST-a	2153.6	2214.3	1020	1.80323	1.796
ST-b	2227.5	2290	1045	1.78916	

Table 0.4: Bulk Density after Immersion

Sample	Cylinders (4" Dia)				
	B (mass of surface-dry sample in air after immersion) **gm**	**C** (mass of surface-dry sample in air after immersion andboiling) **gm**	**D** (apparent mass of sample in water)**gm**	**Bulk density after immersion** = $[\frac{B}{C-D}] \times \rho$ (ρ = 1 mg/m^3 = 1 g/cm^3) **mg/m3**	**Average**
CS-a	2215.1	2220.7	1034.6	1.867	1.860
CS - b	2292.1	2300.1	1064	1.854	
S1 - a	2271.3	2271.3	1022	1.818	1.806
S2 - b	2281.7	2282.5	1011.7	1.795	
PK - a	2282.6	2282.6	1025.3	1.815	1.828
PK - b	2361.7	2351.7	1070	1.842	
G - a	2279	2297.5	1059	1.840	1.854
G - b	2354.3	2369.4	1109.8	1.869	
S1+PK-a	2272.7	2275.6	1000	1.781	1.786
S1+PK-b	2345.8	2348.4	1039	1.791	
ST-a	2210	2214.3	1020	1.850	1.843
ST-b	2285	2290	1045	1.835	

Table 0.5: Bulk Density after Immersion and Boiling

Sample	Cylinders (4” Dia)			
	C (mass of surface-dry sample in air after immersion andboiling) **gm**	**D** (apparent mass of sample in water)**gm**	**Bulk density after immersion and boiling** = [$\frac{C}{C-D}$] x ρ (ρ = 1 mg/m^3 = 1 g/cm^3) **mg/m3**	**Average**
CS-a	2220.7	1034.6	1.872	1.866
CS - b	2300.1	1064	1.860	
S1 - a	2271.3	1022	1.818	1.807
S2 - b	2282.5	1011.7	1.796	
PK - a	2282.6	1025.3	1.815	1.825
PK - b	2351.7	1070	1.834	
G - a	2297.5	1059	1.855	1.867
G - b	2369.4	1109.8	1.881	
S1+PK-a	2275.6	1000	1.783	1.788
S1+PK-b	2348.4	1039	1.793	
ST-a	2214.3	1020	1.854	1.846
ST-b	2290	1045	1.839	

Table 0.6: Apparent Densities

Sample	Cylinders (4" Dia)			
	A **(**mass of oven-dried**)** **gm**	**D** (apparent mass of sample in water)**gm**	**Apparent density** = [$\frac{A}{A-D}$] x ρ = g_2 ρ = 1 g/cm^3	**Average**
CS-a	2153.6	1034.6	1.924	1.919
CS - b	2227.5	1064	1.914	
S1 - a	2219.6	1022	1.853	1.84
S2 - b	2228.1	1011.7	1.831	
PK - a	2226.6	1025.3	1.853	1.86
PK - b	2292.1	1070	1.875	
G - a	2224.6	1059	1.908	1.92
G - b	2295	1109.8	1.936	
S1+PK-a	2224.7	1000	1.816	1.82
S1+PK-b	2295.1	1039	1.827	
ST-a	2153.6	1020	1.899	1.89
ST-b	2227.5	1045	1.883	

Table 0.7: Volume of Permeable Pores

Sample	Cylinders (4" Dia)			
	g1 (Bulk Density Dry)	**g2** (Apparent density)	**Volume of permeable** pore space (voids), % = [$\frac{g2-g1}{g2}$] x 100	**Average**
CS-a	1.81570	1.92457	5.65684	5.765
CS - b	1.80204	1.91448	5.87313	
S1 - a	1.76000	1.85337	5.03784	4.659
S2 - b	1.75331	1.83171	4.28015	
PK - a	1.77094	1.85349	4.45376	4.551
PK - b	1.78832	1.8755	4.64836	
G - a	1.79621	1.90854	5.88565	5.585
G - b	1.82200	1.93638	5.90689	
S1+PK-a	1.74404	1.81652	3.99004	4.03
S1+PK-b	1.75279	1.82716	4.07025	
ST-a	1.80323	1.89978	5.08216	5.050
ST-b	1.78916	1.88372	5.01985	