WATER DAMAGE EVALUATION OF CONCRETE INFRASTRUCTURE

by

SHAKYA ROSHAN

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ABSTRACT

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Supervising Professor: Ali Abolmaali

This study presents an experimental program to evaluate the effect of a special waterproofing material, International Chem-Crete Pavix (CCP), on the durability of concrete. The experimental program identified the concrete mix design commonly used for pavement and other infrastructure as set by Texas Department of Transportation (TXDOT). The tests conducted include the water absorption and air void (ASTM C 642), freeze-thaw (ASTM C 666), chloride penetration (ASTM C 1202), and petrographic (ASTM C 457) test. The tests were performed on both cored and laboratory treated and untreated specimens.

The absorption test was performed on the concrete specimens with water cement ratio of either 0.35 or 0.5. The results of this test include percent absorption, specific gravity, and percent permeable void in the concrete. For freeze-thaw test, the

optional length change test was performed. The test was performed for 300 freeze-thaw cycles. Measurement including length and weight were obtained for approximately every 50 cycles. Chloride ion permeability test was performed on two years old cored and 28 day cured laboratory prepared treated and untreated specimens. The test was conducted on the top 2 inch layer of the concrete specimens. The test result was shown in terms of charge passing, measured in coulombs, through a two inch section of concrete specimens. All tests were done by maintaining the potential difference of 60 volts DC for 6 hours across the ends of the specimens. For petrographic test, procedure A, linear-traverse method was performed. The test was performed on both cored and laboratory prepared treated and untreated specimens.

The test result from the absorption test showed that the absorption capacity and permeable air void of the concrete specimens can be reduced by more than 50% with the application of waterproofing material. Freeze-thaw test results showed that the deterioration rate of untreated specimens is nearly double than that of treated specimens. The test results from chloride permeability test of both two years old cored and 28 days laboratory prepared specimens showed that the permeability is reduced significantly by the application of waterproofing material. The test results from the petrographic test showed that the application of waterproofing material has less effect on air void content and spacing factor of concrete. In general, the treated specimen performed superior to the untreated specimen.

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CHAPTER 1

GENERAL

1.1 Introduction

Some concrete infrastructures such as buildings and pavements that were installed early in the twentieth century are still in use. Most modern concrete structures have a anticipated service life of 25 to 40 years. Deterioration of the concrete structures such as buildings, bridges, roads, tunnels, etc, is an enormous problem worldwide. It is estimated that hundreds of billion of dollars are spent to repair and rehabilitate concrete structure damaged by water.

Abrams [1], in the early twentieth century designed concrete with a uniform distribution of aggregate particles to provide a longer service life for concrete. An exploration into the problem of serviceability showed that modern concrete pavements are removed from service because of failures in concrete pop-outs and degradation of concrete at joints. Joint degradation provides increased access for water to enter the concrete matrix, leading to accelerated freeze-thaw deterioration. Even with properly design air-entrained concrete, the water in the concrete matrix is exposed to freezing temperatures, which expands, causing micro-fractures around the ice formations. The accumulative effect of repeated freeze-thaw cycles will eventually cause concrete failure.

Permeability of concrete can be linked to the durability performance of concrete infrastructure. Water entering the concrete mass also acts as the delivery system for deleterious materials. Historically, it was assumed that higher compressive strength concrete would be more durable, but this theory is currently being challenged. Mehta [2] in his research showed that modern causes of deterioration in pavements are due to corrosion of reinforcing steel, freeze-thaw action, alkali-aggregate reactions and sulfate attack. These causes of deterioration can be linked directly to the intrusion of water into the concrete matrix. If water permeating the concrete mass is causing deterioration, then concrete with low permeability should expect to perform better in aggressive environments.

If water entering the concrete matrix is the problem, then further analysis of the modes by which water can enter the mass must be examined. Cracks are one source of water intrusion. The initial cracks, which create pathways for water intrusion, are caused by thermal stresses developed during the transition of freshly placed concrete to service conditions. These cracks will develop further and interconnect due to environmental stresses during the service life of the concrete.

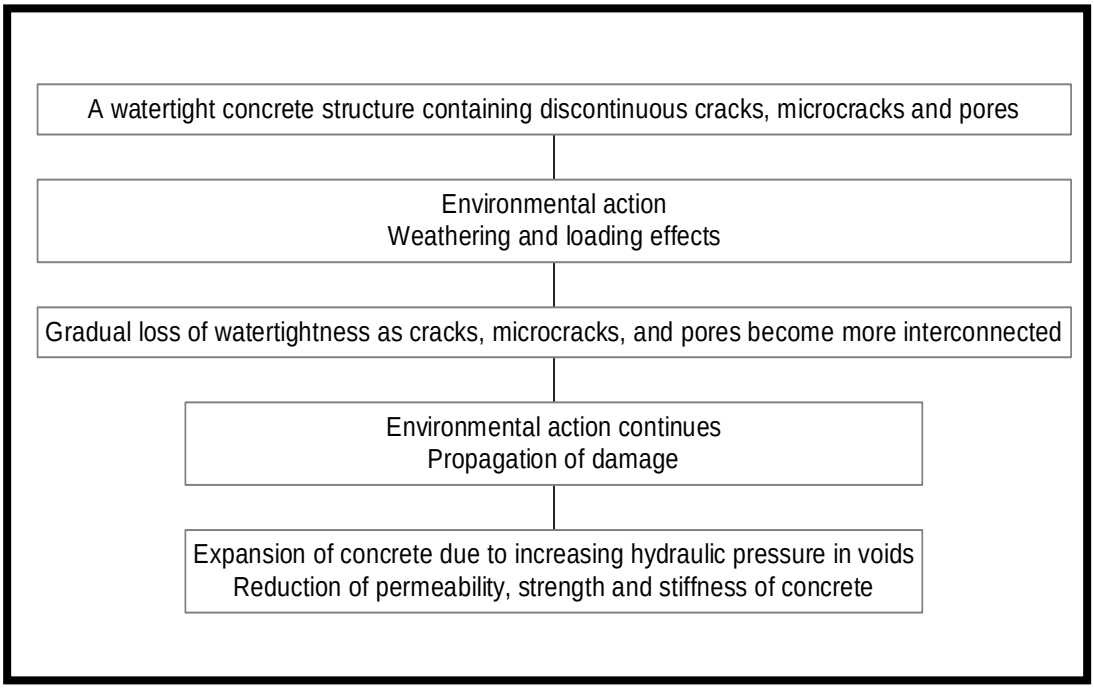

Figure 1.1 Holistic Model of Concrete Deterioration from Environmental Effects [2]

In Figure 1.1, P. Kumar Mehta [2] presents a model of concrete deterioration caused by environmental effects, which demonstrates the proliferation of cracks. The concrete mass begins with discontinuous cracks, micro-cracks, and pores, which establishes the initial permeability. As the environmental stresses act, cracking and permeability increases. Hence, to minimize permeability, these pathways must not interconnect and allow intrusion of water into the concrete matrix. The cementitous materials are the permeable part of the concrete matrix and the aggregates are considered relatively impermeable constituents of concrete.

One alternative to obtaining durable concrete is to use dense graded mix versus gap graded one. This idea has not been accepted in general by the department of transportation due to dependability of the quality of regional coarse aggregates. The

other alternative is to apply special waterproofing substance in form of spray to treat hardened concrete. The objectives of this research are to conduct a preliminary study for comparing durability characteristics of treated and untreated waterproofed laboratory concrete specimen and cored samples form existing concrete structures.

1.2 Literature Review

1.2.1 Concrete (Durability and Water Damage Evaluation)

Concrete is a versatile and widely used construction material [3]. Its excellent record of durability is remarkable when one considers the variety of severe exposures to which it is subjected. There are, however, processes that can produce considerable damage if precautions are not taken.

Al- Zaharani et al. [4] showed that the concrete structures in environments with adverse geomorphic and climatic conditions such as severe ground and ambient salinity and high temperature-humidity regimes are prone to early deterioration. Such aggressive environments induce several deterioration problems, and the most frequent and damaging one is the corrosion of reinforcement steel, which cause early deterioration of concrete structures. The research also showed that major causes of deterioration of concrete structure are the corrosion of steel, freeze and thaw action, alkali-aggregate reactions and sulfate attack. All these cause of deterioration of concrete structure can be directly linked to the access of water into the concrete.

Tamon [5] in his investigation showed that most process that can cause the deterioration in concrete produces an ultimate excessive expansion and cracking which ultimately lead to the ingress of water into the concrete matrix. Wetting and drying

cycles of water in concrete cause not only cyclic deformation (shrinkage/elongation) but also internal stresses due to unequal deformation. The effect of the internal stresses may cause small cracks if the stresses exceed concrete tensile strength. It has been shown that freezing and thawing cycles and alkali silica reaction increases the volume of concrete and creates internal damages in the form of small cracks and plastic deformations. The transportation of chemical substance and gases such as chloride ion, water, oxygen and carbon dioxide in concrete cause material deterioration and corrosion of steel reinforcement in concrete

Permeability of concrete is also one of the most important factors indicates of durability of concrete. Studies conducted by Mehta [6] indicated that in high quality concrete, the transport of gases and ions by diffusion is an exceedingly slower process than that by permeation through an interconnected network of micro cracks.

Mirsura et al. [7] examined the mineral admixture free normal weight concrete mix with water cement ratio of 0.55 and air entraining admixture free fly ash and slag bearing normal weight concrete with a water cement ratio 0.55. The study showed that the chloride permeability changed almost constantly with the repeated cycles of freezing and thawing up to about 600 cycles for any air content. On the other hand fly ash and slag bearing normal concrete mixes with higher air contents showed little increase in chloride permeability with the number of freeze and thaw.

Banthia and Mindess [8] showed that the coefficient of permeability for cement paste specimens subjected to one freeze–thaw cycle at an age of 4-72 hours after casting had permeability which was at least an order of magnitude higher than normally cured

concrete. The above mentioned studies showed that permeability is one of the key factors for the durability and deterioration characteristics of concrete used in infrastructure.

Canadian Association of Cement [9] showed that when the water in the moist concrete freezes, it produces osmotic and hydraulic pressures in the capillaries and pores of the cement paste and aggregates. If the pressure exceeds the tensile strength of the paste or aggregate, the cavity will dilate and rupture. This accumulative effect of successive freeze and thaw cycles and disruption of paste and aggregate eventually cause significant expansion and deterioration of concrete.

The concrete damage evaluation shows that ingress of water in the concrete is an important factor for the deterioration of concrete. As stated above all the major causes for the deterioration of concrete such as the corrosion of steel reinforcement, freeze-thaw action, alkali-aggregates reactions, and sulfates reaction can be directly linked to the entry of water in the concrete. There are several ways to obtain durable and water tight concrete. This project aims at evaluating the use of a special water proofing substance in new and existing concrete structures.

1.2.2 Waterproofing Material

History of waterproofing material goes back to 7,000 BC; "Urbaids" of Mesopotamia used bitumen as a mortar, and as a waterproofing for boats, buildings, etc. There is more evidence of uses of different types of water proofing materials in early civilization. Salmon [10], in his study showed that the first real need for waterproofing materials dates back to the days of Noahs Ark. The 40 days of constant rain inspired

people to take some course of action to prevent water from entering their habitat. In the early days people relied upon thatch, such as straw, reed, leaves and other dried vegetable matter as a barrier against water entering their home.

A report by Salmon [10] showed that over time more sophisticated waterproofing materials were adopted. These included: animal skins, timber shingles, and natural stones like slate. The architectural designs of the day, such as high pitched roofs, helped overcome some of the shortfalls and limitations of the materials that were used. Over the centuries other waterproofing materials were used such as metals e.g. copper, lead, zinc, and tin.

The discovery of oil, coupled with the advances of chemistry saw the arrival of numerous petroleum derived waterproofing products such as bituminous, butyl rubber, neoprene rubber, hypalon etc. With the technological improvements and breakthroughs, waterproofing membranes such as polyurethanes, acrylics and polyesters will become as antiquated as leaves and animal skins are today

Waterproofing is the formation of an impervious barrier which is designed to prevent water entering or escaping from various sections of structures. Saricimen [11] in his investigation showed that the main function of water proofing materials is to prohibit water and any soluble salts from penetrating the concrete to cause corrosion, leaking and other problems. A water proofing materials can be very effective in minimizing the rate of corrosion once it has initiated by prevention access of moisture and oxygen to the steel surface. There are several types of waterproofing materials, which are commonly used for protecting concrete structures. The most common

concrete waterproofing sealants are cement based, epoxy resin, polyurethane resin, acrylic resin, and silane/siloxane, sodium silicate etc. These generic types have considerable variations in terms of the price, durability performance, and method of application.

Iob et al. [12] investigated the manufacturer's claim of waterproofing material that some constituents of the product react with moisture in concrete to form fibrous crystals that grow throughout the pores and cracks of concrete to reduce its permeability and thus prevent ingress of water and chloride ions into concrete structures and thus reducing corrosion of steel bars.

Iob et al. [12] also performed a spectroscopic study of water proofing material which indicated that the product was made up of both inorganic and organic constituents. The study showed that dual action on waterproofing material constituents reduced the corrosion of reinforcing steel bars in concrete. In this dual action, fumatric acid/fumarate system acted as a buffer agent and maintained the pH of concrete around its initial value, and fiber like Na-fumarate crystals and melamine formaldehyde improved the impermeability of concrete significantly by blocking the pores and sealing the surface of concrete.

Mohammed et al. [13] investigated the different types of waterproofing materials to improve the concrete durability by reducing the rate of reinforcement corrosion and sulfate attack. They found out that none of the penetrating sealers investigated were totally effective in preventing carbonation of concrete. However, silane/siloxane with an acrylic topcoat and acyclic coating performed better than other

sealer. For reducing the deterioration of concrete due to sulfate attack they suggested silane/siloxane with acrylic topcoat as a better sealant than other since the reduction in compressive strength due to sulfate attack in concrete specimens coated with silane/siloxane with an acrylic coating topcoat was 8.3% versus 41% in the uncoated specimens. The chloride diffusion in the concrete specimens coated with silane, silane/siloxane with an acrylic topcoat, and acrylic coating was lower than in the uncoated specimens and those coated with other sealers and penetrate.

M.M. Al-Zahrani et al. [14] conducted a study to evaluate steel reinforcement corrosion and some physical properties of concrete specimens coated with two polymer-based, a cement-based polymer-modified, and a cement based waterproofing coatings. The result showed that polyurethane base coating system is by far superior to the other three coating system. The water absorption result of polyurethane base coating specimens showed the value of water absorption of 0.17% compare to 7.43, 1.98, 6.41 and 0.70% of uncoated, cement based polymer modified, cement based and epoxy based coating respectively. The water permeability results showed that all the coating system performed better and showed no water penetration except cement based coating system. The study also showed that the chloride permeability was negligible in two polymers based coating compare to the cement based polymer modified and cement based coating after five months of wetting and drying conditioning. The adhesive value from the test showed that the adhesion of the polymer based coatings was stronger than that of cement based surface coating surface. The polyurethane based coating showed the highest adhesion for the unconditioned specimens.

Al-Dulaijan et al. [15] studied the performance of five resin based surface coatings. The results showed that the adhesion of all the epoxy-resin-based coatings on the concrete substrate performed better than that of the acrylic-resin-based surface coatings. The adhesion values of the resin-based coatings ranged from 1.25 to 2.03 MPa. The chloride permeability in the concrete specimens coated with the selected resin-based surface coating was ranged between 12 and 233 Coulomb.

Umoto et al. [16] evaluated the performance of small repaired reinforced concrete test beams under marine condition. They studied different types of coating system including epoxy, silicone, urethane, acrylic rubber, acrylic resin, polyester, and polymer-modified cement and mortar. After 18 months, uncoated specimens exhibited corrosion at the interface and in the concrete substrate, whereas, no evidence of corrosion was observed in any of coated beams.

Cabrera and Hassan [17] performed accelerated American Association of State Highway and Transportation Officials (AASHTO) diffusion tests on concrete specimens coated with several coatings. The result showed that the epoxy coating demonstrated higher chloride resistance, and the sodium silicate based coating showed the least performance among the tested system. After 12 months of exposure to environmental chamber, simulating the Arabian Gulf conditions, the reduction in chloride penetration for different surface treated concrete specimens was in the range 15-98% as compared to uncoated ones.

Swamy et al. [18] examined the performance of concrete slab coated with acrylic-based coating against chloride and atmospheric carbon dioxide attacks. After

long time exposure to repeated cyclic wetting by sodium chloride solution followed by drying, the result showed no chloride penetration into the concrete beneath the coating. During the period of field exposure, the uncoated concrete specimens showed carbonation depth ranging from 7.6 to 8.9 mm, whereas the acrylic-based coating prevented the penetration of carbon dioxide into the concrete.

1.3 Goal and Objective

The objective of this project is to conduct a study for comparing durability characteristics of uncoated and coated using new-laboratory and existing cored specimens. The existing cored specimens were provided by International Chem Crete Inc. The new laboratory specimens were prepared in the materials lab at University of Texas at Arlington. The mix design of laboratory specimen was done for an expected slump value of 5 inch, air content 5% and water cement ratio of 0.5. The coating material used for this project is special water proofing material Chem-Crete Pavix ™ (CCP) was provided by International Chem Crete Inc. The main purpose of this research is to carry out experimental investigations to study and evaluate the damaged caused by water in concrete infrastructure with and without special water proofing substance CCP. This experimental study includes test such as water absorption (ASTM C 642), freeze-thaw (ASTM C 666), chloride penetration (ASTM C 1202), and petrographic examination (ASTM C 457) on treated and untreated samples. In this experimental evaluation the International CCP coated concrete specimens will be subjected to water and moisture related failures such as freeze and thaw, water

absorption, and the deterioration caused by chemical reactions and environmental condition in real life situation.

CHAPTER 2

EXPERIMENTAL PROGRAM

2.1 Introduction

The experimental procedure of this study is used as a tool towards comparative evaluation of the durability properties of concrete with and without using special waterproofing material Chem-Crete Pavix (CCP). In this experimental program, the CCP coated concrete specimens will be subjected to water and moisture related failures such as freeze and thaw, water absorption, and deterioration caused by chemical reactions and environmental condition in real life situation.

To accomplish the goal of obtaining maximum durable and water tight concrete, this study incorporated the practice of using a special waterproof material, CCP, as defined above. A brief background on CCP is presented in the Section 2.2. A description of materials, mix proportions, specimen preparation and configuration, testing equipment, and testing procedures are discussed in this chapter. The following tests were conducted to evaluate the durability characteristics of the treated and untreated specimens used in this study

1. Slump Test (ASTM C 143)
2. Compressive Strength (ASTM C 39)
3. Flexural Strength (ASTM C 78)
4. Specific Gravity, Absorption, and Voids of Hardened Concrete (ASTM C 642)

5. Water Absorption of Hardened Concrete Treated With a Water Repelling Coating (ASTM C 6489-99)
6. Freeze-Thaw of Concrete (ASTM C 666)
7. Rapid Chloride Ion Permeability (ASTM C 1202, ASSHTO T 277)
8. Petrographic Analysis of Air-Void System in Hardened Concrete (ASTM C 457)

2.2 Background On International Chem-Crete Pavix (CCP)

Chem-Crete Pavix (CCP) [19] is unique water based chemical product that is intended to provide a permanent treatment and ultimate protection of large scale concrete substrates. CCP protects against temperature and moisture associated problems such as thermal cracking, damage caused by repeated freeze and thaw cycles, chloride penetration, as well as alkali silica reaction.

CCP is expected to combine the repelling function along with a hygroscopic and hydrophilic moisture blocking mechanism. Its low viscosity is expected to allow it to penetrate easily and deeply into concrete pavements.

The protection property of CCP takes place in two difference mechanism. First, it provides the concrete surface with a repelling feature that prevents water from penetrating into concrete through capillaries by increasing the surface tension of water and other liquid such as jet fuel and oil [19]. This product is reported to blocks [19] water and vapor movements within the capillaries and pores via a crystallization process. The crystal formed by the Pavix treatment is of hygroscopic and hydrophilic properties that provide a double action in moisture blocking [19]. Under the wet

condition, and upon contact with moisture, the hydrophilic behavior is expected to produce crystals that swell and fill the void preventing moisture from passing through. Simultaneously, the hygroscopic property of the crystal provides continual crystal growth towards the source of moisture, resulting in permanent blocking at its source.

Under dry conditions, the crystals release the moisture in a desorption process that makes the crystal shrink to original size. The swelling/shrinkage process of the crystals will allow the concrete to continually breathe.

If the adequate tests are conducted, the following could be the potential advantage of the CCP.

- To prevents penetration of chloride ions from de-icing salts into civil concrete.
- To eliminates damage caused by repeated freezing and thawing cycles in concrete pavement.
- To provide permanent internal waterproofing and moisture blocking from positive and negative sides by hygroscopic and hydrophilic crystallization mechanisms.
- To possess property that prevents water, jet fuel and oil from penetrating the surface.
- To resist aggressive chemicals such as acids, caustic jet fuels and oil.
- To protects reinforcing steel bars against corrosion without any negative effect on existing steel cathodic protection.
- To enhance the adhesion property of joint sealant and road markers.

- To reduces Alkali Silica Reactions thus eliminating silicate dusting.

2.3 Mix Proportions

To fulfill the purpose of this study, a number of mix design procedures were studied prior to the selection of a suitable mix design for this research. Since the waterproofing materials used in this research are primarily used in pavement, the mix design selected for this research was selected on the basis of a typical pavement design mix. Each mix design was conducted for expected slump value of 5 inch, air content 5% and water cement ratio of 0.5. The mix proportion for concrete is presented in Table 2.1.

Table 2.1 Mix Design

INGREDIENTS	lb/yd^3
Water	260
Cement	517
Coarse Aggregate	1850.1
Fine Aggregate	1286.1
Total	3931.1 lb/yd^3

An admixture used for this mixture is 3.0 FL.Ozs /100 cement weights for water reducing and 0.4 FL.Ozs /100 cement weights for air content.

2.4 Aggregates Source and Constituents

The coarse aggregate source for this study was from the Bridgeport pit and the fine aggregate was from the Ferris pit; both located in the central part of state of Texas. The maximum size of coarse aggregate used was 1-inch. Tables 2.2 and 2.3 present the physical properties of each aggregate. The moisture contents of each aggregate were determined before mixing operations on a day-to-day basis to adjust for the amount of free moisture on the aggregates. To attain the target air content and water/cement ratio of the specified mixes, air-entraining admixture in combination with water-reducing admixture were added. The ProAir 260, air entraining admixture and Plastimix 50 water-reducing admixture were used conforming to ASTM C 260 and ASTM C 494 Types A and D, respectively. Type I Portland cement meeting the requirements of ASTM C 150, was used in developing the mix designs.

Table 2.2 Fine Aggregate Sieve Analysis

Sieve no.	Weight Retained (g)	Percent Retained	Percent Coarser	Percent Finer
4	1.1	0.14	0.14	99.86
8	3.7	0.47	0.61	99.39
16	11.2	1.43	2.04	97.96
30	70.1	9.00	11.04	88.96
50	349.2	44.80	55.84	44.16
100	271.00	34.76	90.6	9.4
200	66.3	8.50	99.1	0.9

Cumulative : 259.37

Fineness modulus = 2.6
Bulk Specific Gravity = 2.645
Absorption Capacity = 0.643%

Table 2.3 Coarse Aggregate Sieve Analysis

Sieve no.	Weight Retained (g)	Percent Retained	Percent Coarser	Percent Finer
1 ½	0	0	0	0.00
1	466.1	5.50	5.50	94.5
¾	2063.2	24.34	29.84	70.16
½	3718.1	43.88	73.72	26.28
3/8	1309.3	15.45	89.17	10.83
4	812.1	9.59	98.76	1.24
8	63.6	0.75	99.51	0.41
pan	23.7	0.27	99.78	0.22

Cumulative : 317.28

Fineness modulus = 3.2
Bulk Specific Gravity = 2.69
Absorption Capacity = 0.425%

2.5 Specimen Preparation and Configuration

A total of 8 (4 x 8 in) cylinders, 6 (6 x 12 in) cylinders, 6 (6 x 6x 20 in) beams and 8 (4 x 3 x 11.25 in) beams were constructed. The specimens were demolded 24 hours from casting. Table 2.4 present the total number test specimens and Figure 2.1 shows a photograph of typical test cylinders.

Table 2.4 Number of Test Specimen

Specimen	Number	Test
Cylinder(6 x 12 in)	6	Compression Test
Cylinder(4 x 8 in)	8	Absorption Test
Beam(6 x 6 x 20 in)	6	Flexure Test
Beam (4 x 3 x 11.25in)	8	Freeze and Thaw Test

Figure 2.1 Specimens in Molds

The following presents all the tests conducted to determine the durability of coated and uncoated specimens.

1. Compressive Strength testing (ASTM C 39-01)
2. Flexural Strength testing (ASTM C 78-00)
3. Specific Gravity, Absorption, and Voids in Hardened Concrete (ASTM 642-97)
4. Standard Test method for Determination of Water Absorption of Hardened Concrete Treated With a Water Repelling Coating (ASTM C 6489-99)
5. Resistance of Concrete to Rapid Freezing and Thawing (ASTM C 666-97)
6. Chloride Ion Permeability (ASTM C 1202-97, AASHTO T 277-93)
7. Microscopic Determination of Parameters in Hardened Concrete (ASTM C 457-98)

2.6 Mix Design Development

All the concrete constituents were weighed to the nearest 0.01 pound on an A & D Engineering FG-150KX 300 pound capacity digital scale as shown in Figure 2.2

Figure 2.2 A & D Engineering FG-150KX Digital Scale

The A & D GP-30k digital scale, shown in Figure 2.3, was used when smaller measurements of less than 5,500 grams were required. All measurements of ProAir 260, air entraining admixture, and Plastimix 50, water-reducing admixture were taken using a 50, 100, or 200 mL graduated cylinder, depending on the amount of air-entrainment used.

Figure 2.3 A & D GP-30k Digital Scale

After measuring all the constituents for a 5.5-cubic foot mix design, a 9.0-cubic foot concrete mixer, as shown in Figure 2.4, was used. For the smaller trial mixes, a Stone Thrift mixer (refer to Figure 2.5) with a capacity of 3.0-cubic feet was used. Concrete mixing was performed in accordance with ASTM C 192-97; machine mixing procedures. The procedure is as follows:

1. Place all coarse aggregate in the mixer before starting rotation.

2. Rotate the mixer and add some of the mixing water.
3. After a few revolutions, add half the fine aggregate and admixtures.
4. As the mixer is rotating, add the cement and then the remaining fine aggregate.
5. Add the remaining mixing water.
6. Operate the mixer in the following manner: (1) Rotate mixer for three minutes; (2) Shut down the mixer to allow the concrete mix to set for three minutes with a damp cloth covering the open end of the mixer during the rest period; and (3) Rotate mixer for two minutes to complete the mixing procedure.

After completion of the 8-minute mixing procedure, plastic properties of concrete are tested.

Figure 2.4 Nine Cubic Foot Mixer

Figure 2.5 Three Cubic Foot Mixer

2.7 Slump of Hydraulic Cement Concrete (ASTM C 143-00, AASHTO119-93)

Slump testing was developed to measure the consistency of plastic concrete in a laboratory setting. The test is used to show the consistency in relationship to the amount of water present in freshly mixed concrete with all other constituents closely controlled. Consistency is defined as the tendency of plastic concrete to flow as a fluid. In practice, contractors use the slump of concrete as a measure of workability. This is not an accurate application of the test since the slump may be affected by many variables, most particularly, aggregate gradation.

Materials required to perform this test are a slump cone, a non-absorptive surface, a tamping rod and a tape measure. The slump cone (refer to Figure 2.6) is a frustum of a cone 12 in. tall with top and bottom openings of 4 in. and 8 in. diameters, respectively. The tamping rod is 24 in. long, 5/8-inch diameter with a hemispherical tip. The procedure for performing the test consists of moistening the cone and the non-absorptive base. Place the freshly mixed concrete in the cone in three successive layers equal to $^1/_3$ the volume of the cone. Each layer is consolidated by rodding action 25 times with the first layer being tamped through the layer of concrete. The rodding action of the remaining two layers should penetrate them completely and slightly penetrate the previous layer. After rodding the three successive layers, the excess concrete is struck off with the rod and waste concrete is cleaned from the perimeter. The cone is removed at a rate of 5 ±2 seconds directly upward. A result from a standard slump test method is shown in Figure 2.7. The slump is the difference in height of the mold and the original displaced center of the cone measured to the nearest $^1/_4$ inch.

This test provides a uniform comparison of the batch-to-batch consistency of concrete prepared using the same materials. The test method is applicable to concrete with a maximum size aggregate of 1½ inch. Additionally, the test is valid only for concrete samples having slumps greater than ½ inches and less than 9 inches

Figure 2.6 Slump Test Apparatus

Figure 2.7 Slump Test

2.8 Compressive Strength Tests (ASTM C 39-01)

Compressive strength tests were conducted at 28 days following casting. The concrete test specimens were standard 6 in. x 12 in cylinder specimens. Three specimens were tested at 28 days for verification purposes. The average compressive strength of the three test specimens was computed to report the "compressive strength" of the concrete used in the project.

The compressive strength tests were performed on a 300,000 lb capacity Balwin universal testing machine. The following procedures were followed for all the test specimens of this test:

1. Steel caps meeting ASTM C 1231 requirements with neoprene inserts were centered on the ends of the specimen and the specimen was placed upright in the testing machine.
2. The specimen was centered in relation to the upper spherical block. The load reading was set at zero and the lower platen was adjusted until the top of the specimen contacts the upper bearing block. A photograph of a specimen loaded in the testing machine is shown in Figure 2.8. A load diagram of a specimen subjected to distributed axial compressive loading is shown in Figure 2.9. The specimens are kept in a moist condition after leaving the curing room until testing occurs.
3. The axial compressive load was applied at a continuous rate of 20 to 50 psi/sec until failure. The maximum load at failure was reported along with the type of fracture and any notable defects in the specimen.

Figure 2.8 Compressive Testing Apparatus

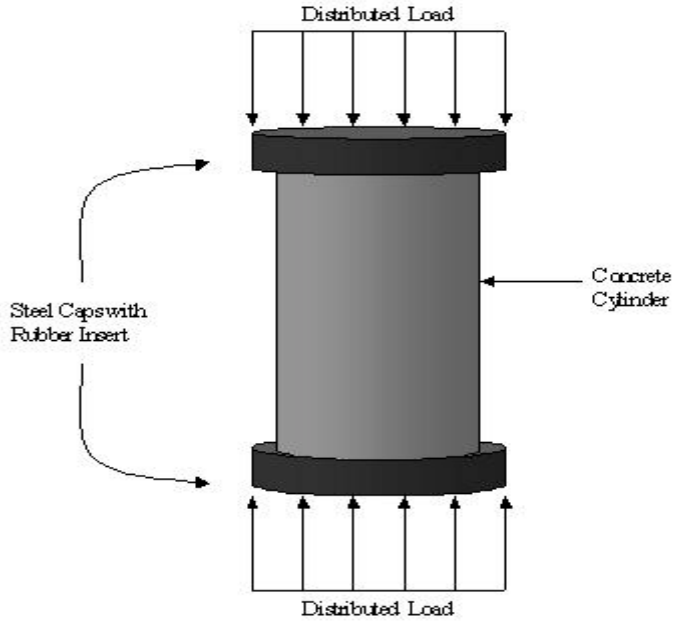

Figure 2.9 Cylinder Subjected to a Distributed Load

2.9 Flexural Strength Tests (ASTM C 78-00)

This test is the standard method for determining the flexural strength or modulus of rupture of concrete, expressed in lb/in^2, which uses a simple beam with third-point loading. The specimens for this test were cast in 6"x 6" x 20" molds and lab cured in accordance with ASTM C 192.

Testing was performed on a 300,000 lb capacity Balwin universal testing machine. The load frame apparatus used had bottom support rollers at 18 in. spacing and top supports spaced at 6 in. The load frame was equipped with one top and bottom support that was rigid and the other two supports that acted as a rocking support. This frame and support allows the beam support to pivot to remove any torsion that may otherwise be caused by slight imperfections in the cast beam. The third point loading method was used to ensure that forces applied to the beam are perpendicular to the failure plane and to eliminate eccentricity. The procedure for this test was as follows:

1. The beams were removed from the curing room to be tested in a moist condition.
2. Marks were made at 1 inches from each end at the bottom surface and 7 inches on the top portion of the beam for alignment of the specimen in the test apparatus. A specimen loaded in the testing machine is shown in Figure 2.10.
3. The beam was loaded continuously at a rate of 125 to 175 psi/min until failure occurred. The maximum load was recorded.

The depth and width of the beam were measured at three locations across the failure plane and the average of the measurements was recorded.

When failure occurs within the middle third of the beam, the modulus of rupture (MOR), *R*, is calculated using the following equation in lb-in. units:

$$R = \frac{P\ell}{bd^2} \qquad (2.1)$$

Where:

P = the maximum applied load
ℓ = the span length of the bottom supports (18 inches)
b = the average base (or width) at the failure plane
d = the average depth at the failure plane.

If failure occurred outside the middle third by not more than 5% of the span length (0.9 inches), then the average distance between the line of fracture and the nearest support is measured on the tension surface of the beam. In this case, the MOR is calculated using the following equation.

$$R = \frac{3Pa}{bd^2} \qquad (2.2)$$

Where:

a = the average distance between the line of fracture and the nearest support and the definition of other variables are the same as those for Equation 2.1.

If the fracture were to occur outside both regions, the results were discarded.

Figure 2.10 Flexure Test

Figure 2.11 Failure of Concrete Specimen

2.10 Specific Gravity, Absorption, and Voids in Hardened Concrete (ASTM C 642-97)

This standard test method determines the specific gravity, percent absorption, and percent voids in hardened concrete. The test method is useful in developing the data needed for mass/volume conversions for concrete. The test results can also be used to indicate variability from place to place within a mass of concrete.

The concrete is tested at a curing age of 28 days. In accordance with the test procedure, a desired sample of hardened concrete with volume not less than 350 cm^3 or approximately 800 grams by weight should be used for testing. A typical untreated test specimen is shown in Figure 2.12. From this sample the following values are obtained:

A = Oven-dry weight

B = Saturated weight after immersion (initial)

C = Saturated weight after boiling the sample for five hours (final)

D = Weight of sample immersed in water

When weighing the sample during oven drying (A), the sample is determined to be dry when two successive weight readings are within 0.5% of the lesser weight obtained. Initial saturation is accomplished by submersion in water for a minimum of 48 hours. Saturated surface-dry measurements are taken at 24 and 48 hours to determine sufficient saturation. Successive saturated surface-dry weight readings must be within 0.5% of the heavier weight or the time must be extended. Final saturation is accomplished by boiling the specimen for five hours. Then the sample is allowed to cool for 14 hours while submersed. The data obtained from this test method is calculated as follows:

$$\text{Absorption after Immersion, \%} = \left[\frac{(B-A)}{A}\right]\times 100 \qquad (2.3)$$

$$\text{Absorption after Immersion and boiling, \%} = \left[\frac{(C-A)}{A}\right]\times 100 \qquad (2.4)$$

$$\text{Bulk Specific Gravity, dry} = \left[\frac{A}{(C-D)}\right]\cdot \rho = g_1 \qquad (2.5)$$

$$\text{Bulk Specific Gravity after Immersion} = \left[\frac{B}{(C-D)}\right]\cdot \rho \qquad (2.6)$$

$$\text{Bulk Specific Gravity after Immersion and boiling} = \left[\frac{C}{(C-D)}\right]\cdot \rho \qquad (2.7)$$

$$\text{Apparent Specific Gravity} = \left[\frac{A}{(A-D)}\right]\cdot \rho = g_2 \qquad (2.8)$$

$$\text{Volume of Permeable Pore Space (Voids), \%} = \left[\frac{(g_2-g_1)}{g_2}\right]\times 100 \qquad (2.9)$$

or $$\left[\frac{(C-A)}{(C-D)}\right]\times 100$$

Figure 2.12 Untreated Test Specimens

2.11 Standard Test method for Determination of Water Absorption of Hardened Concrete Treated With a Water Repelling Coating (ASTM C 6489-99)

This test method provides a procedure for the determination of the water absorption of hardened concrete coated with a water repellent. The intended use of water repellent coating is to reduce the amount of water that absorbs into the substrate. A typical treated test specimen is shown in Figure 2.13.

The concrete is tested at a curing age of 28 days. After curing, the specimens were open using steel brush to give similar condition as broom over pavement surface and clean with soft brush and compressive air. Then specimens were kept in oven for 24 hour at temperature maintain at 75^{O}C. After oven dried the specimens were cool to room temperature and mass of the specimens were determined as W_A until two successive weightings at intervals of 2 h show an increment of loss not greater than 0.2% of the previously determined weight. For coating of water repellent material on concrete the specimens were submerged in the container containing water repellent material Chem Crete Pavix (CCP) for 6 hour (for minimum coverage ratio provided by Chem–Crete International). After removing the specimens from the container the specimens were allow to dry completely for 7 days. After complete drying the mass of the specimens were determined as W_1. The specimens were submerged in container containing water and mass of the specimens were determine on every 24 hours interval until there is no change in mass. The final mass of the specimen is determined as W_2. The data obtained from this test method is calculated as follows:

$$\text{Percent Absorption, \%} = \left[\frac{W_2 - W_1}{W_A}\right] \times 100 \qquad (2.10)$$

W_2 = Weight of dry specimen before coating

W_1 = Weigh of dry specimen after coating

W_A = Weight of specimen after immersion

Figure 2.13 Treated Test Specimens

2.12 Resistance of Concrete to Rapid Freezing and Thawing (ASTM C 666- 97)

This test method covers the determination of the resistance of concrete specimens to deterioration caused by rapidly repeated cycles of freezing and thawing in the laboratory by using ASTM C 666-97, Procedure A, Rapid Freezing and Thawing in Water. For a detailed procedure of testing, please refer to ASTM C 666.

For this test we performed the optional length change test. The optional test for freeze and thaw test is change in length and weight test. While these properties cannot be used to predict the life cycle of a pavement, they can be useful in comparing the freeze-thaw durability of various mixes and aggregate sources.

The equipment used to perform this test procedure consists of an automatic freeze-thaw apparatus, shown in Figure 2.14, which meets ASTM C 666, a scale and a length change comparator meeting ASTM C 490, shown in Figure 2.15.

Figure 2.14 Freeze and Thaw Apparatus

Figure 2.15 Length change comparator

It is assumed the test procedure will have little or no damaging effects on frost-resistant concrete, defined as (1) any concrete not critically saturated with water (that is, not sufficiently saturated to be damaged by freezing) and (2) concrete made with frost-resistant aggregates and having an adequate air-void system that has achieved appropriate maturity and thus will prevent critical saturation by water under common conditions. As the specimens are exposed to the repeated freeze-thaw cycles, we expect to detect changes in the length and weight due to the deteriorating influences of water expansion during freezing.

For a design mix, eight 4”x 3”x 11¼” specimens, with embedded gauge studs at each end, were cast in the laboratory in accordance with ASTM C 192. A typical test specimen is shown in Figure 2.16.

Figure 2.16 Freeze and thaw Test Specimen

At 24 hours of age, the samples were removed from the molds and placed in our temperature controlled curing room. At 28 days of age the specimens were either placed directly in the testing apparatus for immediate testing, or placed in a freezer to keep the hydration process dormant until the test apparatus was available for the next group of specimens. The nominal freezing-thawing cycle for this procedure consists of alternately lowering the temperature of the specimens from 40^{o}F to 0^{o}F and raising it from 0^{o}F to 40^{o}F neither less than 2 hr nor more than 5 hours. There were 300 freeze-thaw cycles performed to all test specimens (ASTM C 666). Initial measurements include length and weight was taken in accordance to ASTM C 490. These measurements were also obtained at approximately 50 cycle intervals during the test procedure.

It is not recommended that freeze-thaw testing be continued on specimens after there is 0.10% expansion or change in length. The length change in percent and the weight change in percent can be obtained from equation 2.11 and 2.12 respectively.

Length Change in Percent (L_c)

$$L_c = \left[\left(\frac{l_2 - l_1}{L_g}\right)\right] \times 100 \qquad 2.11$$

Where:

L_c = length change of the test specimen after C cycles of freezing and thawing, %

l_1 = length comparator reading at 0 cycles

l_2 = length comparator reading after C cycles

L_g = the effective length between the innermost ends of the gage studs as shown in the mold diagram in specification C 490

Weight change in Percent (W_c)

$$W_c = \left[\left(\frac{W_2 - W_1}{W_2}\right)\right] \times 100 \qquad 2.12$$

Where:

W_c = Weight change of the test specimen after C cycles of freezing and thawing, %

W_1 = Weight of specimen at 0 cycles

W_2 = Weight of specimen at C cycles

2.13 Rapid Chloride Ion Permeability (ASTM C1202-97, AASHTO T 277-93)

The Rapid Chloride Ion Permeability (RCIP) test relates the determination of the electrical conductance of concrete to provide a rapid indication of its resistance to the penetration of chloride ions. This test is suitable for evaluation of materials durability characteristics as it indicates the permeability characteristics of material samples.

Testing apparatus, specimen conditioning, and test procedure are in accordance with ASTM C 1202-91 and AASHTO T 277-93. The instrument used in testing was the PROOVE IT system, version 1.3, manufactured by German Instruments In-Situ Test Systems. Photographs of the preparatory apparatus and the testing apparatus are presented in Figures 2.17 and 2.18, respectively.

Figure 2.17 Preparatory Apparatus

Figure 2.18 Proove It Test Cell

The purpose of this test is to monitor the amount of electrical current that passes through a 2 in. thick concrete specimen with 4 in. diameter over a 6-hour period of time. A potential difference of 60 V DC is maintained across the ends of the specimen, one of which is immersed on a 3.0% Sodium Chloride (NaCl) solution with the other immersed in 0.3 N Sodium Hydroxide (NaOH) solution. The numerical results (total charge passed, in coulombs) from this test method are categorized in Table 2.5

Table 2.5 Chloride Ion Penetrability Based on Charge Passed

Charge Passed (Coulombs)	Chloride Ion Permeability
> 4000	High
2000 - 4000	Moderate
1000 - 2000	Low
100 – 1000	Very Low

The age of the sample (test specimen) may have significant effects on the test results, depending of the type of concrete and curing procedure. Most concretes, if properly cured, become significantly less permeable with time. Specimens used in this test method consist of old concrete cores which were provided by International Chem Crete Inc., with a diameter of 4 inches and height of 9 inches, extracted from a parking lot. Both treated and untreated cored samples were provided for the test.

In addition to old cored specimens, 4 X 8” cylinders were cast for more tests. The cylinders were cured for twenty eight days as other sample. After twenty eight-day curing period, half of the specimens were treated with waterproofing material. Then samples were cure for week in lab condition and send to Hanson Aggregates Technical Services where they were cut using a wet-cut masonry saw. The laboratory specimens along with the old cored specimens from International Chem Crete Inc. were further

cured in the laboratory condition before the chloride penetration test was performed. Each old cored and laboratory specimens is cut into four slices of 2-in. (± $^{1}/_{8}$") thickness and two slices of 2-in. respectively using a wet-cut masonry saw with a diamond tipped blade. Two individual cores from each treated and untreated samples were evaluated to determine a mean permeability for each mix design and to evaluate the repeatability of RCIP.

The "*conditioning*" of the test specimens starts with careful inspection for rough surfaces and voids. The rough edges are sanded down and the voids are filled with an epoxy resin. A thin layer of epoxy resin can be used on each specimen to eliminate any stray current. During this procedure, it is made sure that no epoxy is applied to the surfaces of the specimen slice.

Four-2 inch thick slices are conditioned at one time. The four specimens are placed in a vacuum desiccator and hooked up to a vacuum pump. The pump is run for 3 hours to remove air from the voids in the concrete. Distilled water that has been boiled for ½ hour and then cooled for de-aeration is used to flood the specimens. The specimens are completely submerged in the de-aerated water while the vacuum pump is run for an additional hour. After one hour, the pump is turned off, the valves are opened to allow air to enter and the system is returned to ambient pressure conditions. The specimens soak for another 18 ±2 hours.

After conditioning the specimens they are removed from the container and excess water is removed from the specimen surface. Each specimen is installed in a PROOVE IT cell with the top surface facing the sodium chloride side of the cell.

Gaskets are used to prevent the fluids in the cell ends from leaking into the common space between the cell halves, which may cause stray voltage around the specimen. Four bolts on each test cell are then tightened, compressing the two gaskets sealing the cell. When all specimens are secured in the PROOVE IT cells, the appropriate ends are filled with the sodium chloride and sodium hydroxide solution. The cells are connected to the PROOVE IT power supply, which links to an IBM-compatible computer running the PROOVE IT software. Test data is collected at five (5) minute intervals throughout the 6-hour duration of the test. During the test, the following data are shown: actual voltage, actual current, temperature, elapsed time, 6-hour predicted coulombs, and coulombs passed at the present. Upon completion of the test, the test specimen is given a permeability classification and the data can be viewed and saved to a file.

2.14 Microscopic Determination of Parameters to the Air-Void System in Hardened Concrete (ASTM C 457-98)

This test method describes procedures for microscopic determination of the air content of hardened concrete, specific surface of voids, spacing factor of voids, and paste content for each test specimen. Procedure A, the Linear-Traverse Method, was the method used for in this study.

The determination of a specimen's specific surface and spacing factor of voids are significant to this study. The spacing factor and specific surface are generally regarded as the most significant durability indicators of a cement paste matrix to freeze-thaw exposure. The spacing factor and specific surface of voids are inversely related and allow two different ways for viewing the air void system of a concrete specimen.

The general trend of the specific surface and spacing factor of voids is as follows: when the specific surface of air voids increases then the spacing factor of the voids decreases. The maximum value of the spacing factor for moderate exposure of concrete is usually taken to be 0.008 inch. Larger values may be adequate for mild exposure, and smaller results may be required for severe exposure to weather, especially if the concrete is in contact with deicing chemicals.

Procedure A, the Linear-Traverse Method, consists of the determination of the volumetric composition of concrete by summing the distances traversed across a given component along a series of regularly spaced lines in one or more planes intersecting the test specimen. The data gathered are the total length traversed (T_t), the length traversed through the air voids (T_a), the length traversed through paste (T_p), and the number of the air voids intersected by the traverse line (N). These data are used to calculate the air content and various parameters of the air-void system of hardened concrete.

The parameters of the air-void system of concrete are related to the vulnerability of the cement paste matrix to damage by freeze-thaw conditions. This test method can be used to develop data to estimate the potential of frost damage to concrete and why it has occurred. The test method can also be used as an adjunct to the development of products or procedures intended to enhance the frost resistance and durability of concrete

Specimens used in this test method consist of old concrete cores provided by International Chem Crete Inc. and laboratory cast samples. After 28-days of curing of

lab specimens, half of the specimens were treated with waterproofing material. Then specimens were cure for additional week in lab condition before they were cut parallel a long its length producing a half-cylindrical shape test specimen using a masonry saw. A typical picture of concrete cross-section under 100X magnification is presented in Figure 2.19.

For a detailed procedure of Microscopic Determination of Parameters to the Air-Void System in Hardened Concrete, please refer to the Annual Book of ASTM Standards.

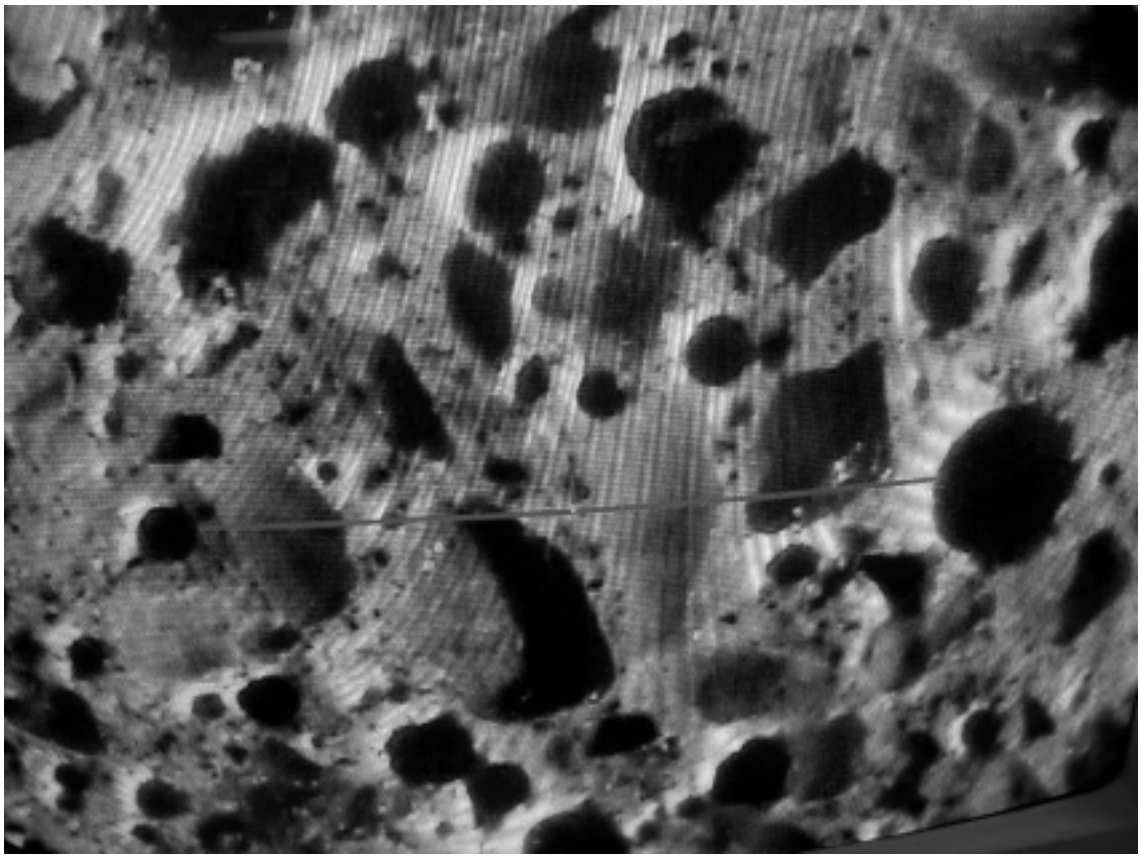

Figure 2.19 Typical Cross-Section of Concrete at 100X Magnification

CHAPTER 3

EXPERIMENTAL TEST RESULTS

3.1 Introduction

The experimental test results illustrate the relationships between mix design proportions, compressive strength, flexural strengths, permeability, total air voids and petrographic analysis, and freeze and thaw data for treated and untreated specimens. The detailed description of mix design procedure was presented in Section 2.3 of Chapter II. The mix design proportion is presented in Table 2.1 in which the e recorded data is based on Volumetric proportioning for 1 cubic yard. Concrete used in mix design was 5.5–ft^3 and was batched into one mix. This much quantity was needed to conduct all required standard test procedure. In addition to this, additional specimens for absorption test were prepared with different mix design. The detail description of this mix design proportion is presented in Table A-9 of Appendix A. The experimental results presented through Chapter III will be compiled from test result of each standard test presented in Chapter II. The average and detail summaries of experimental test results are given in Table B-1 through B-20 of appendix B. The results presented in this report describe the behavioral properties of treated and untreated concrete.

3.2 Compressive Strength Test Results

The compressive strength tests specimens consist of 6-inch diameter cylinders with 12-inch height. These cylinders were tested at standard 28 day. Three cylinders were tested to represent an average compressive strength of the mix. The target 28 day compressive strength of the mix was 3500 psi. The compressive strength of the mix must be within a range of +/- 10% of the targeted compressive strength [20].

The 28 day compressive strength test result for the given concrete mix design used in the research are provided in Table 3.1 and Figure 3.1, which show the compressive strength of all three specimens was above the target 28 day strength and 28 day compressive strength of all three specimens is 3890 psi. Since concrete used in this research achieved targeted 28 day compressive strength, the concrete was identified as acceptable to be used for further laboratory testing.

Table 3.1 28 Day Compressive Strength Test

Specimen no.	Diameter (inch)	Area ($inch^2$)	Maximum Load (lbf)	Compressive strength (psi)
C-1	6	28.287	111,100	3930
C-2	6	28.287	107,900	3816
C-3	6	28.287	110,900	3922
Average	6	28.287	109965.67	3890

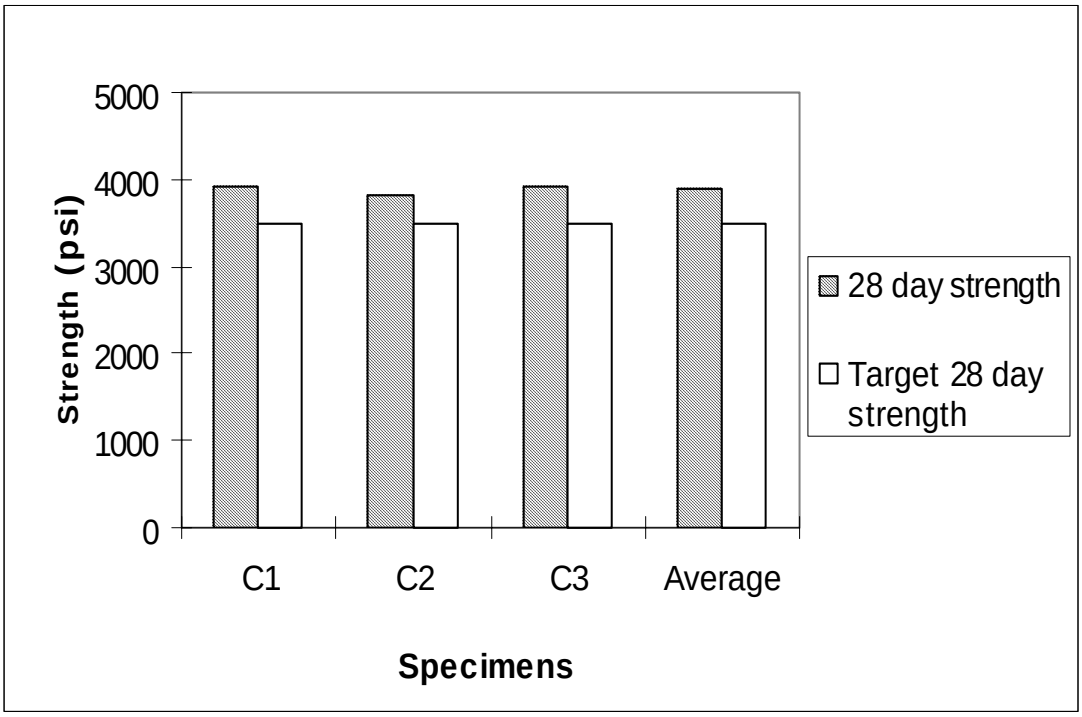

Figure 3.1 Comparison of Compressive strength

3.3 Flexural Strength Test Results

The flexural strength test was conducted with 6" x 6" x 20" concrete beam specimens as explained in Section 2.9 of Chapter II. The third point loading standard test method was used to determine the modulus of rupture, which is a measure of flexural strength in concrete. The test was conducted at the same testing periods as compressive strength tests and the three beams specimens were tested at each test period to give an average strength result for each mix design. The minimum 28 day flexural strength required in the pavement construction by the TXDOT is 555 psi. The strength of concrete can vary due to differences in specimen sizes, preparation, moisture content, and curing method.

The 28 day flexural strength experimental test results for the concrete used in this research are given in Figure 3.2 and Table 3.2, which show that all the three specimens tested for 28 day flexural test pass the minimum 28 days flexural strength provided by the TXDOT. The average of three specimens is 573 psi which is well above the minimum requirement of 555 psi required by the TXDOT. Therefore, the concrete specimens used in this research were used for further testing.

Table 3.2 28 Day Flexural Strength Test

Table 3.2 28 Day Flexural Strength Test Specimen No.	Maximum Applied load (lbf)	L	Bd^2 (6" x 6")	MOR (psi)
F-1	7000	18"	$216in^2$	585
F-2	6800	18"	$216in^2$	567
F-3	6800	18"	$216in^2$	567
Average	6867	18	216	573

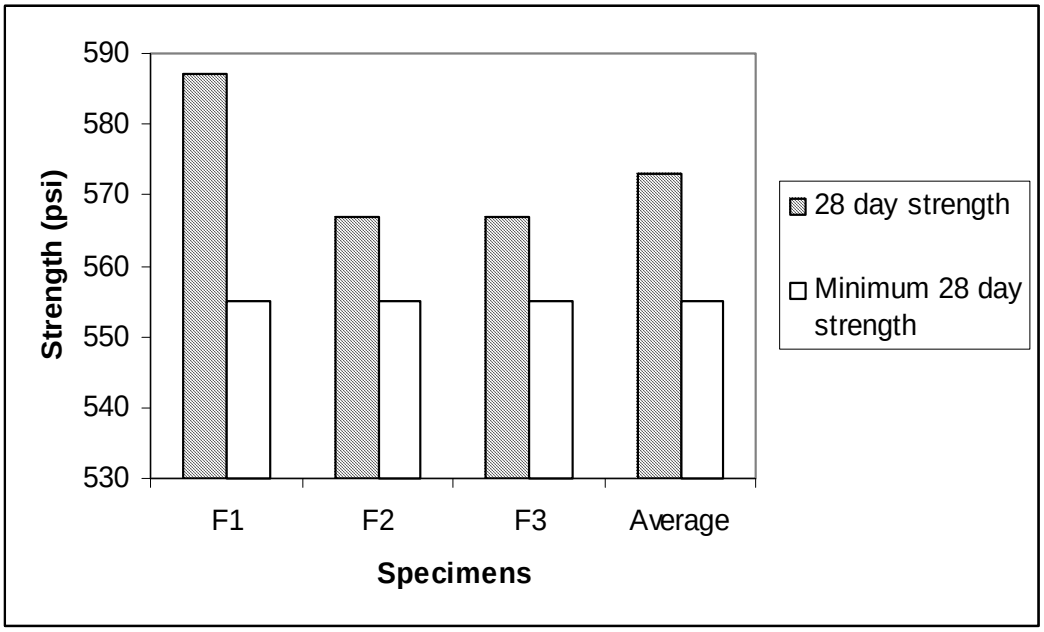

Figure 3.2 Comparison of Flexural Strength

3.4 Air Void System Test Results

The test results of this procedure include specific gravity, percent absorption, and percent void in hardened concrete. This result is useful in developing mass/volume conversions for concrete. The test results for percent voids can be useful in understanding the permeability test results. The larger percentages of total voids in hardened concrete will aid in the increase of permeability through a concrete specimen.

The test specimens used for this test consist of six 4" x 8" cylinder and six 6" x 6" x 4" beam specimens obtained from remain of the flexural test beam (6" x 6" x 20") specimens. In addition to this, additional test sample for absorption test was prepared with different mix designs. The detail description of this mix design proportion is presented in Tables A-9 of Appendix A. After 28 day of curing period, half of the specimens were treated with waterproofing substance CCP and were cured for

additional 7 day before they are ready for the test. The detail descriptions of the test procedure are given in Section 2.10 and 2.11 of Chapter II.

The experimental test result for concrete mix used in this research and additional mix design for absorption test are presented in Table B-10 of Appendix B. The test results presented in Appendix B show that by the application of waterproofing material CCP, the absorption capacity of concrete was significantly reduced by more than 50%. The volume of permeable pore space (percent voids) is also reduced with the application of CCP. The comparison of the test result of treated and untreated specimens are presented in Figures 3.3, 3.4, and 3.5, respectively.

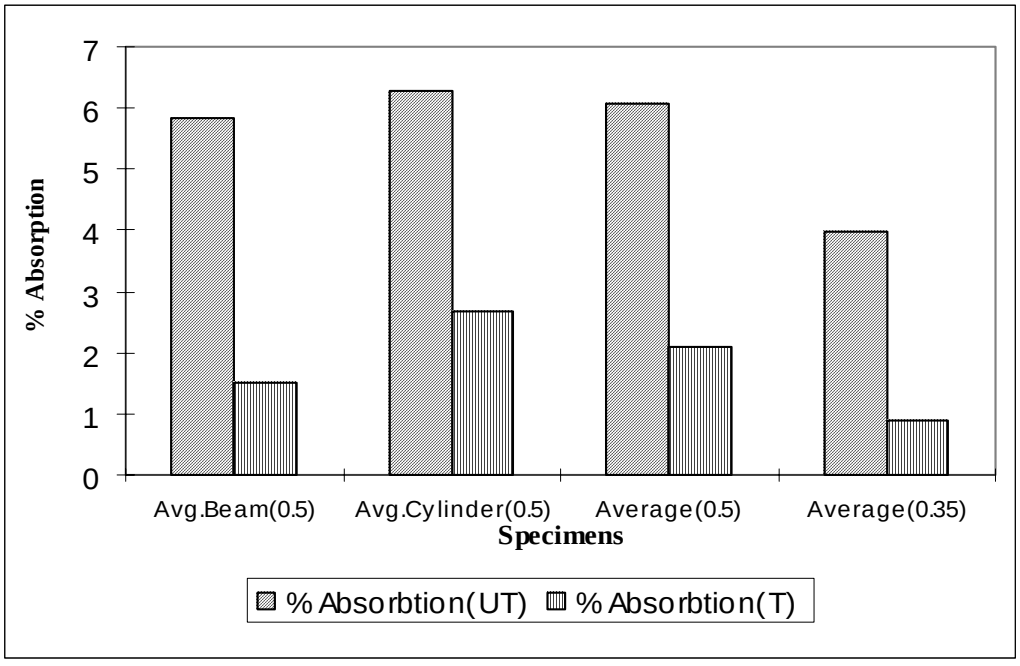

Figure 3.3 Absorption Test Result

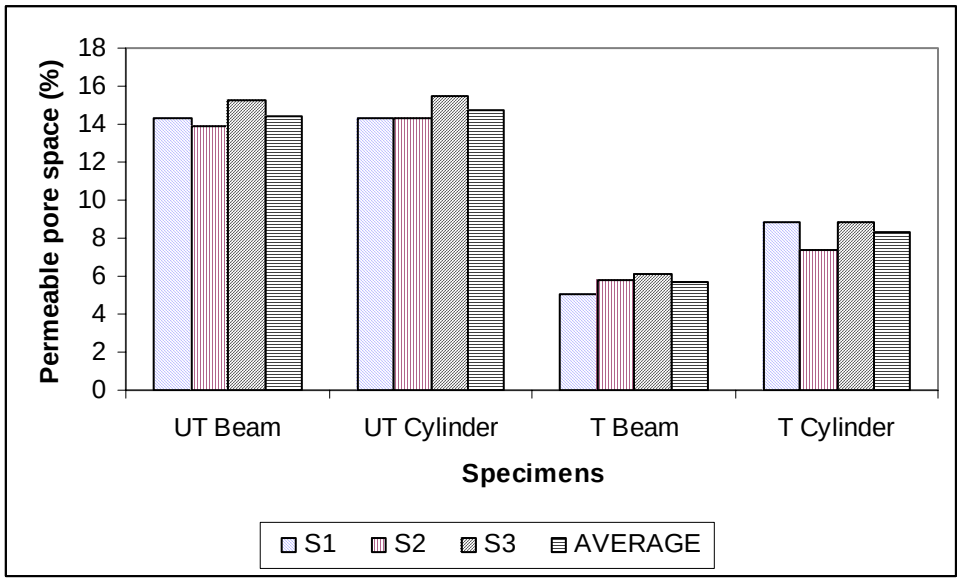

Figure 3.4 Volume of Permeable Pore Space Test Result

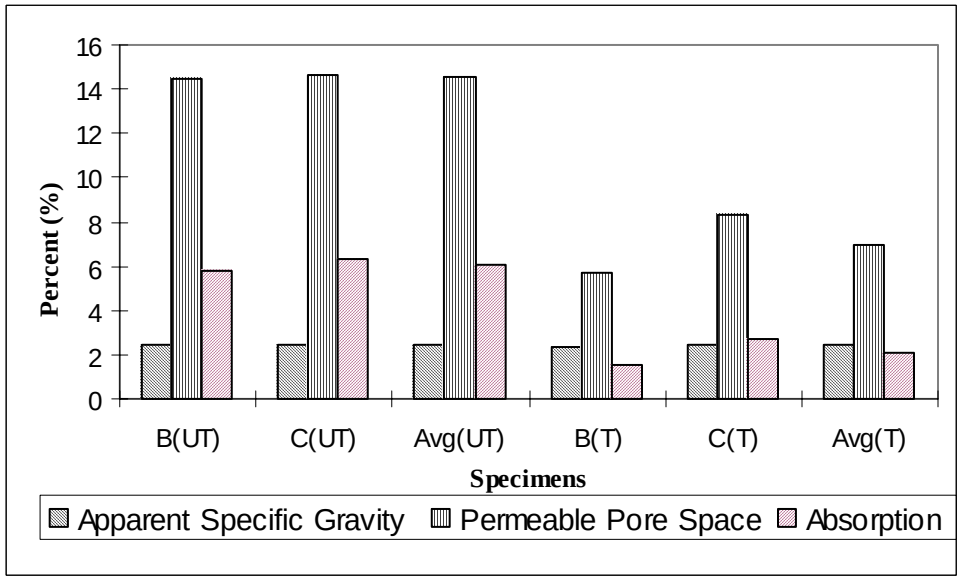

Figure 3.5 Air-Void System Test Result

Figure 3.3 shows the comparison of absorption rate between the treated and untreated specimens and mixes. It can be seen that the treated specimens have lower

absorption characteristics as compared to the untreated specimens. It was noticed that the absorption rate is reduced by more than 50% in both cases. From Figure 3.4, we can see that volume of permeable pore space is reduced by the application of waterproofing substance. This shows that untreated specimens are more permeable than treated specimens. This is due to unique properties of waterproofing material CCP that combines the repelling function along with a hygroscopic and hydrophilic moisture blocking mechanism.

3.5 Freeze and Thaw Test Results

Freeze-Thaw Test was performed in Material laboratory in University of Texas at Arlington (UTA). The equipment used to perform this test procedure consists of automatic Freeze and Thaw apparatus and a length change comparator. For this test we performed the optional length change test. There were 300 freeze-thaw cycles performed for all the specimens. Measurement including length and weight were obtained for approximately every 50 cycles.

For a design mix, eight 4”x 3”x 11¼” specimens, with embedded gauge studs at each end were cast in the laboratory in accordance with ASTM C 192. It is not recommended that freeze-thaw testing be continued on specimens after there is 0.10% expansion or change in length. . The detail descriptions of the test procedure are given in Section 2.12 of Chapter II.

The test results of treated and untreated specimens for freeze and thaw test are presented in Tables B-13 and B-14 of Appendix B. The results show the change of length and weight of concrete for different cycles of freeze and thaw test. These Tables

show that the change of length in the treated sample is less than of the untreated sample. There is no change in weight for the treated specimens after 300 cycles whereas, some change in weight is found in the untreated specimens. The percentage change in length and weight in treated and untreated specimen are presented in Figure 3.6 and Figure 3.7, respectively.

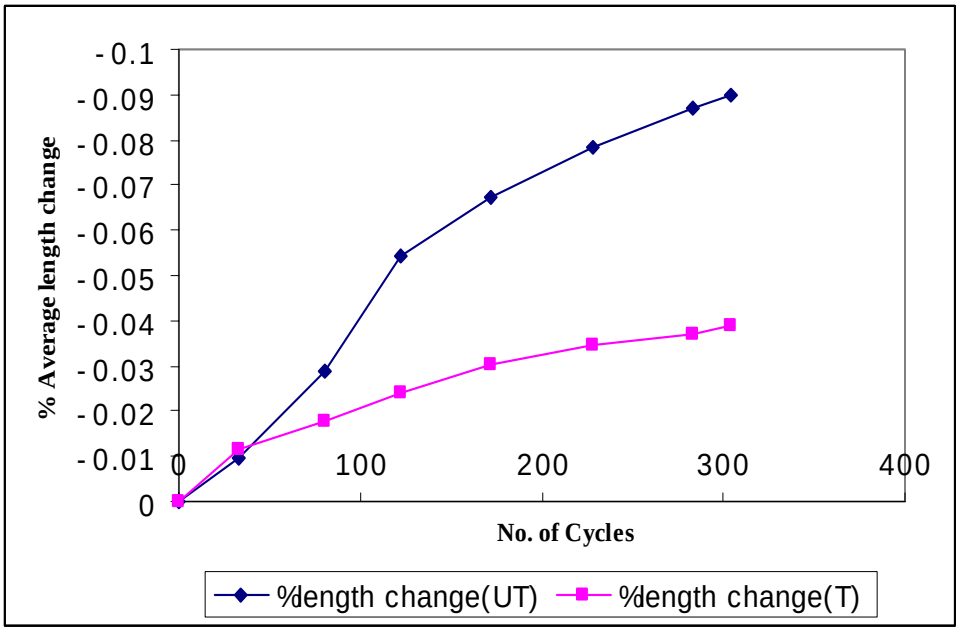

Figure 3.6 % Length Change of Treated and Untreated Specimens

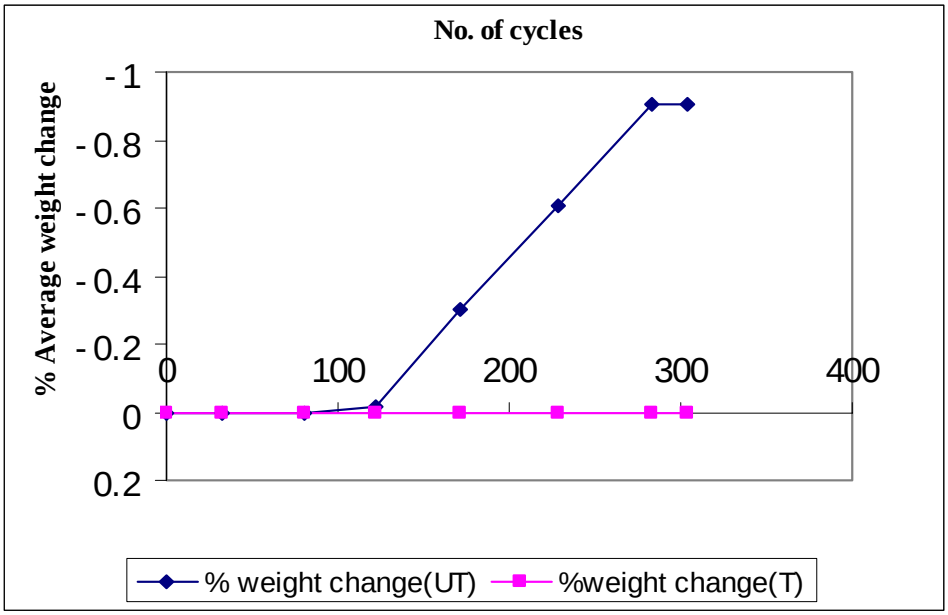

Figure 3.7 % Weight Change of Treated and Untreated Specimens

From Figure 3.6, it can be observed that the average % length change of the untreated specimen is -0.09% whereas the treated specimen is -0.039. Only one untreated specimen UT-2 changes more than 0.10% after 300 cycles, maximum allowable % change in length by ASTM C 666 standard for continuation of test. Figure 3.7 shows the % weight change of treated and untreated specimens. It can be seen that there is no change in weight of the treated specimen, but some change of weight are seen in untreated specimens. The detail graphical representations of % length change and weight change for every reading taken are presented from Figure 3.8 to 3.14 and Figure 3.15 to 3.19 respectively.

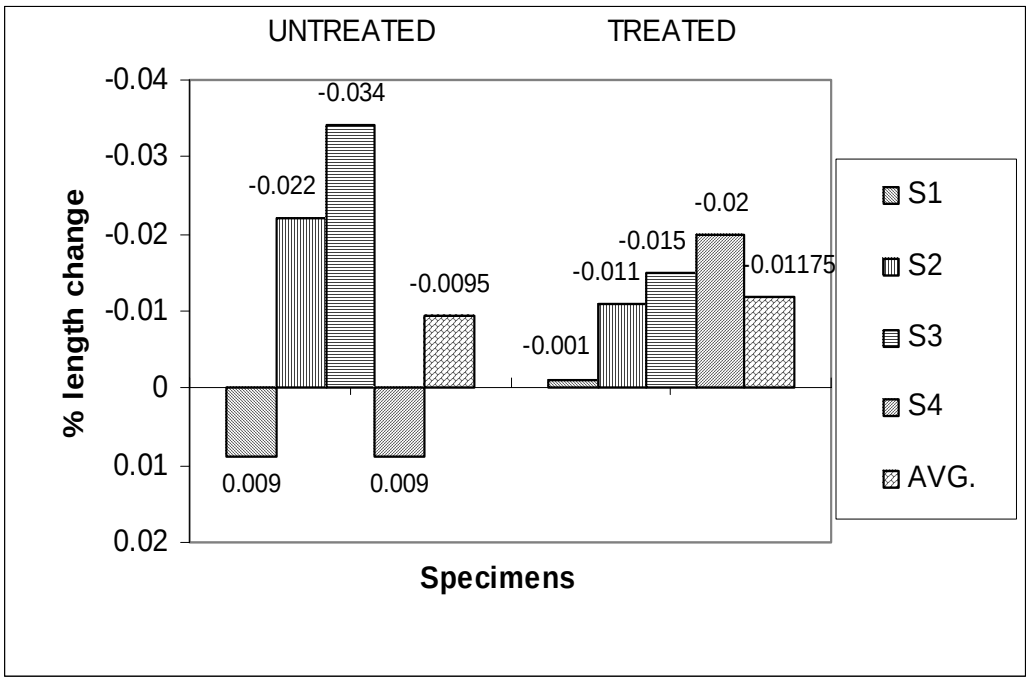

Figure 3.8 % Length Change of Specimens for 33 Cycles

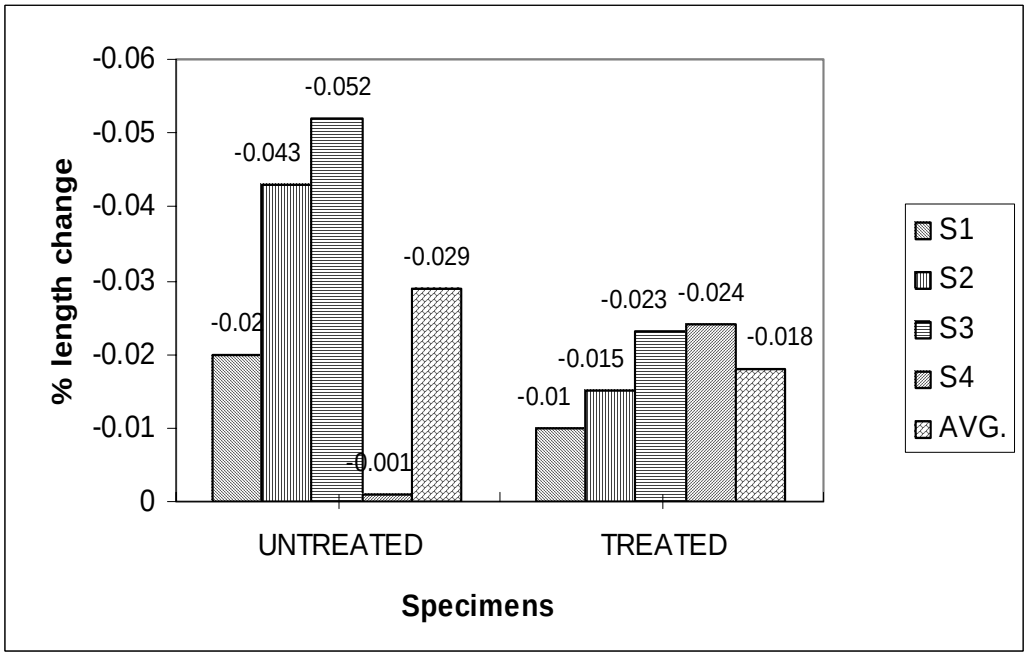

Figure 3.9 % Length Change of Specimens for 80 Cycles

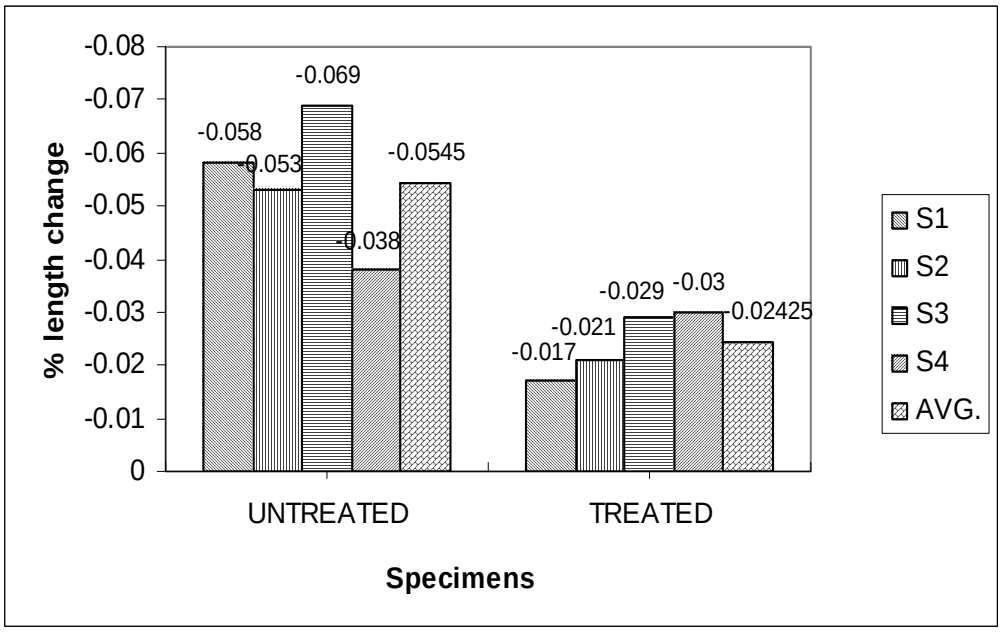

Figure 3.10 % Length Change of Specimens for 122 Cycles

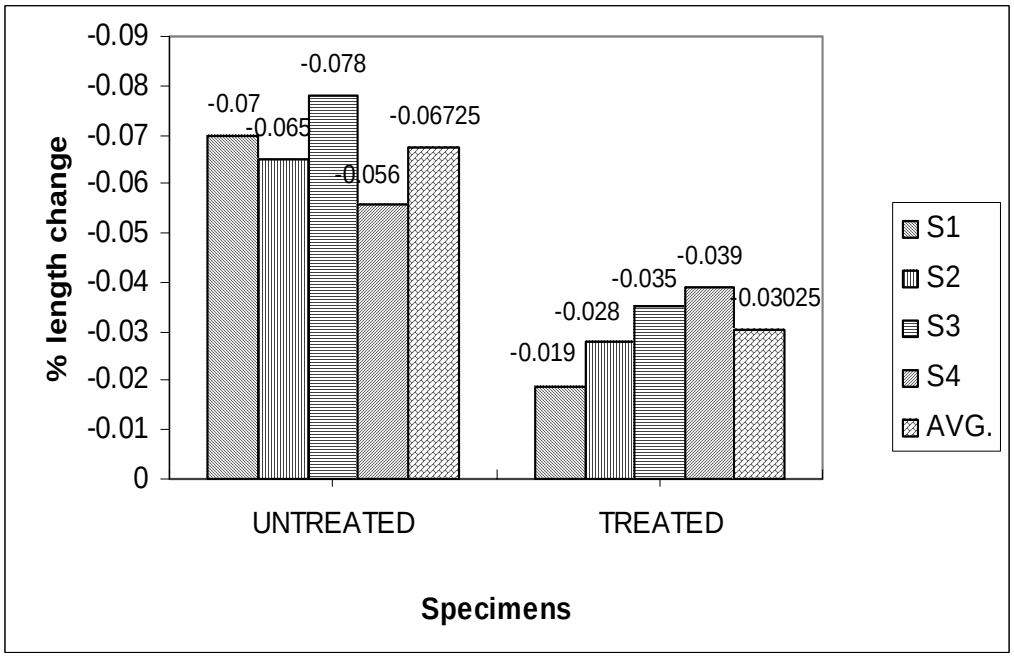

Figure 3.11 % Length Change of Specimens for 172 Cycles

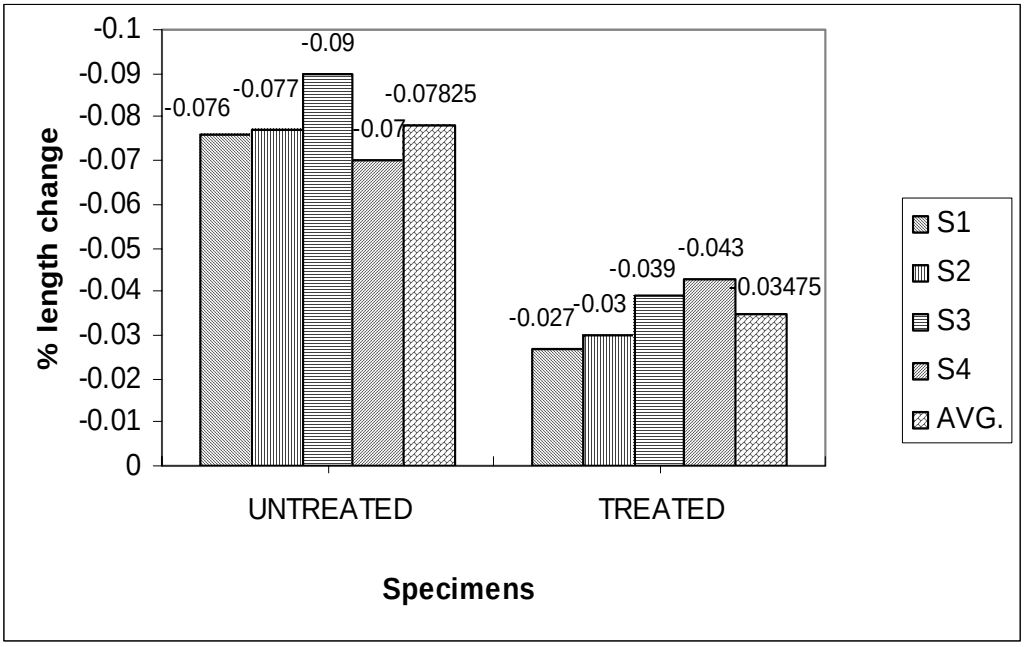

Figure 3.12 % Length Change of Specimens for 228 Cycles

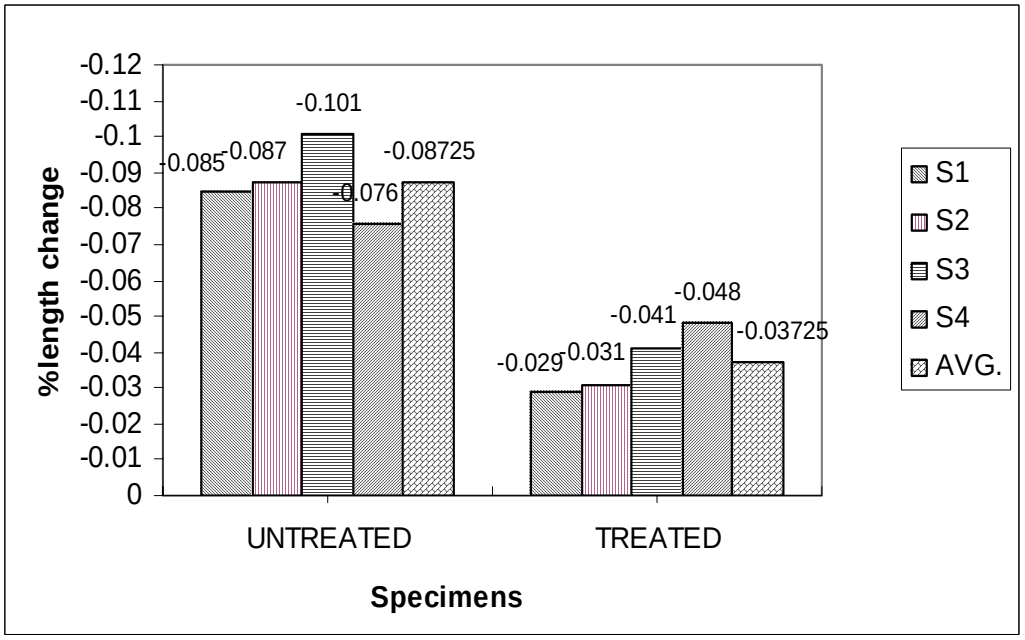

Figure 3.13 % Length Change of Specimens for 283 Cycles

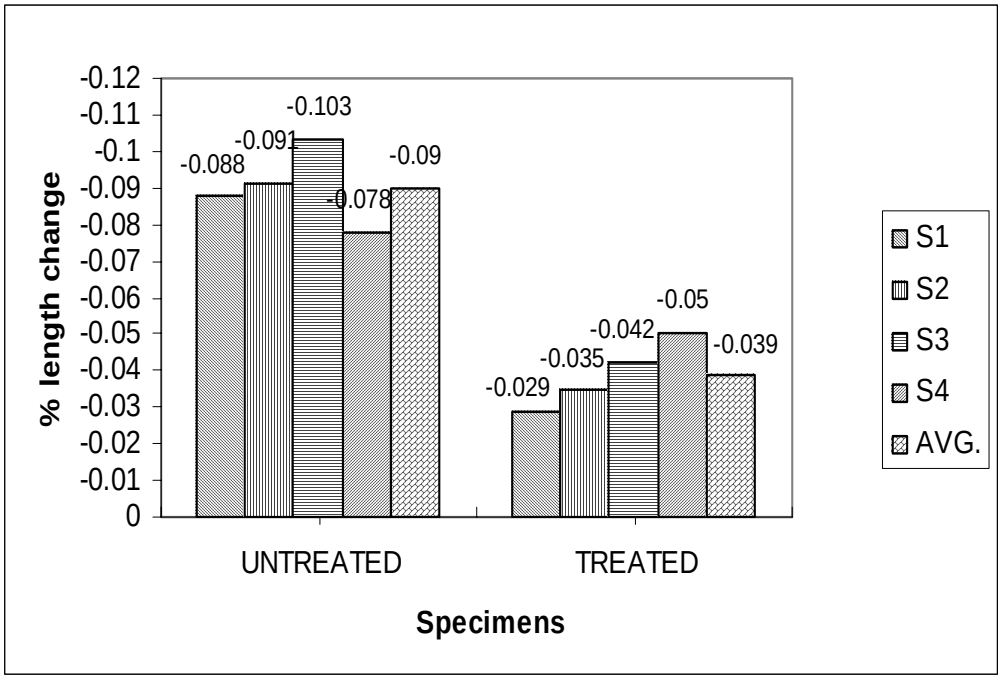

Figure 3.14 % Length Change of Specimens for 304 Cy**cles**

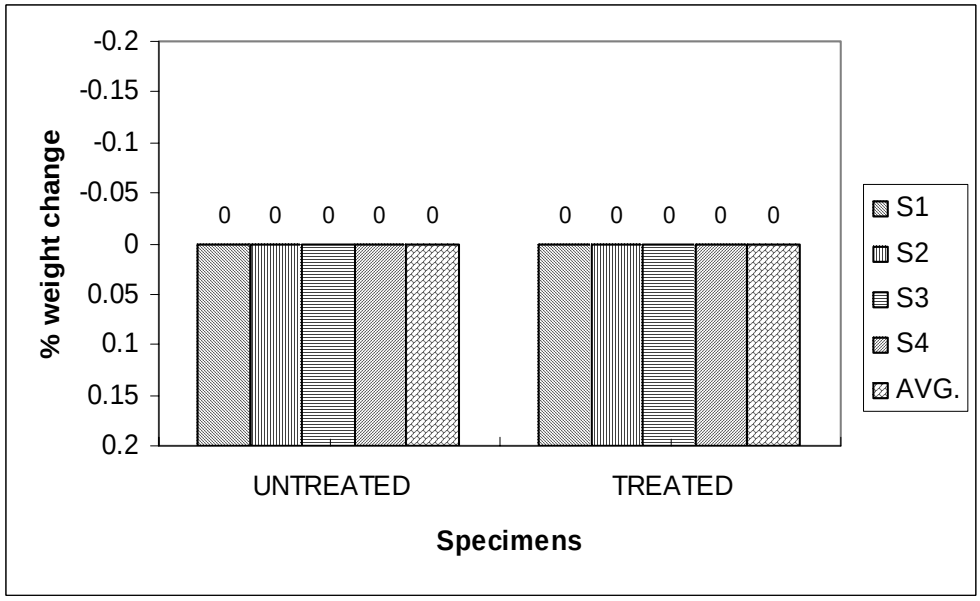

Figure 3.15 % Weight Change of Specimens for 33 and 80 Cycles

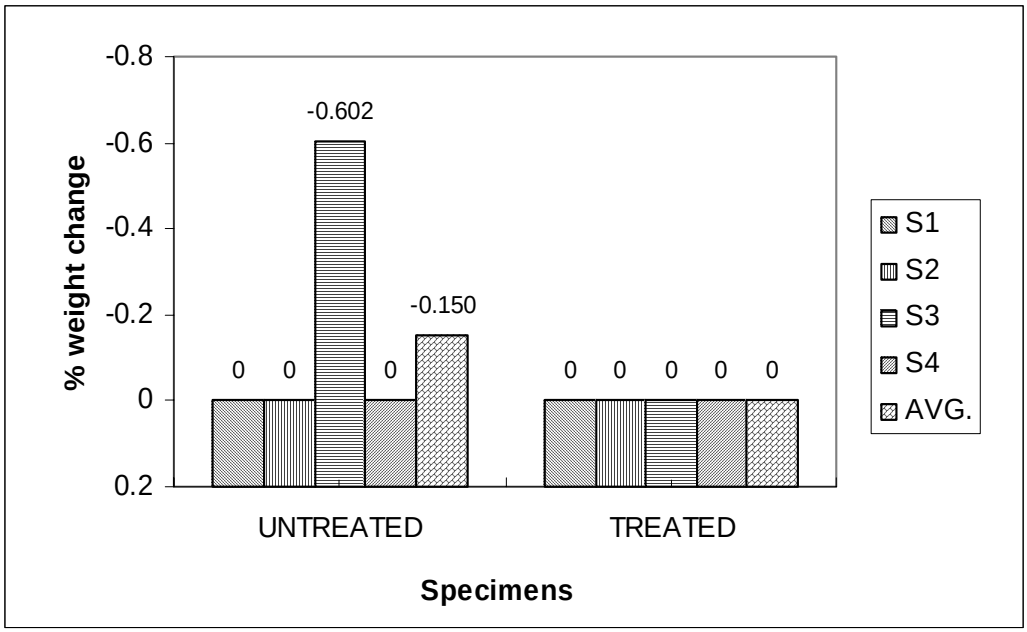

Figure 3.16 % Weight Change of Specimens for 122 Cycles

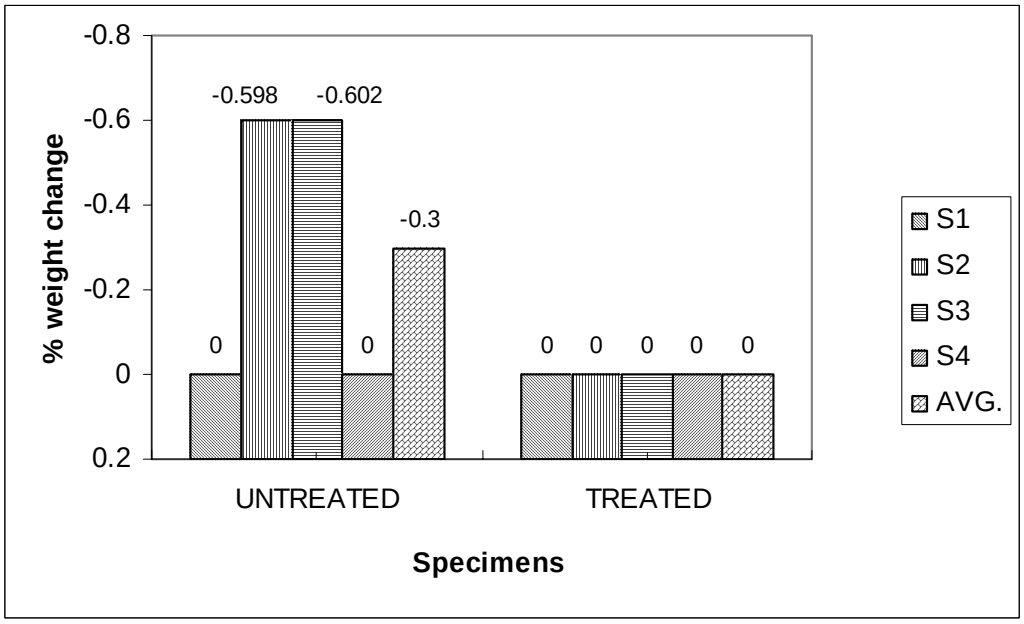

Figure 3.17 % Weight Change of Specimens for 172 Cycles

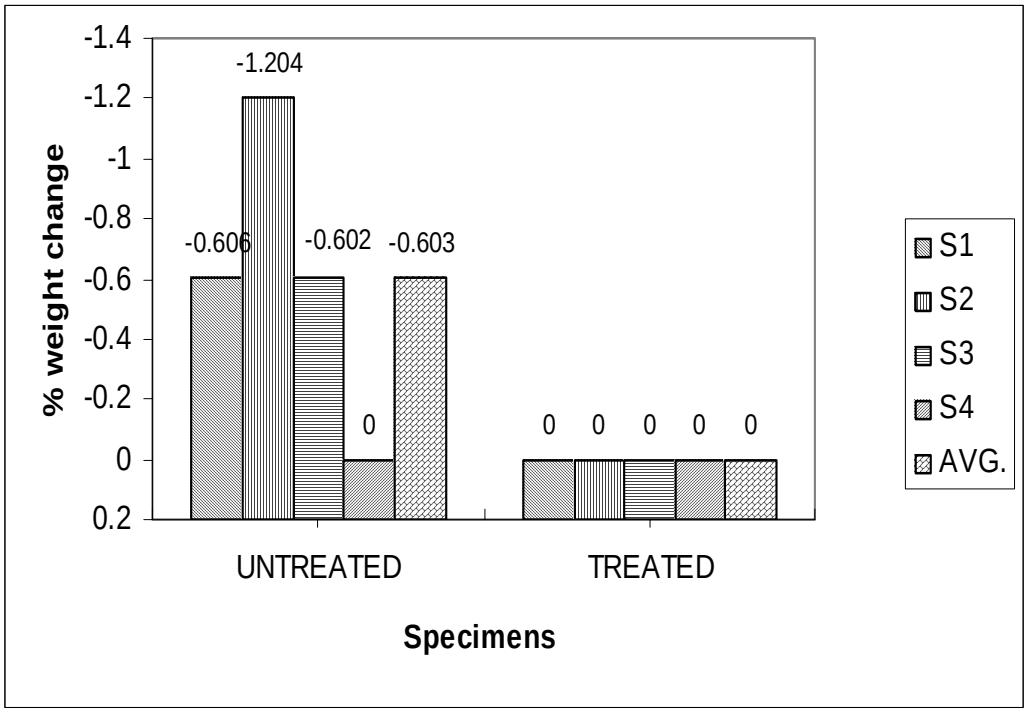

Figure 3.18 % Weight Change of Specimens for 228Cycles

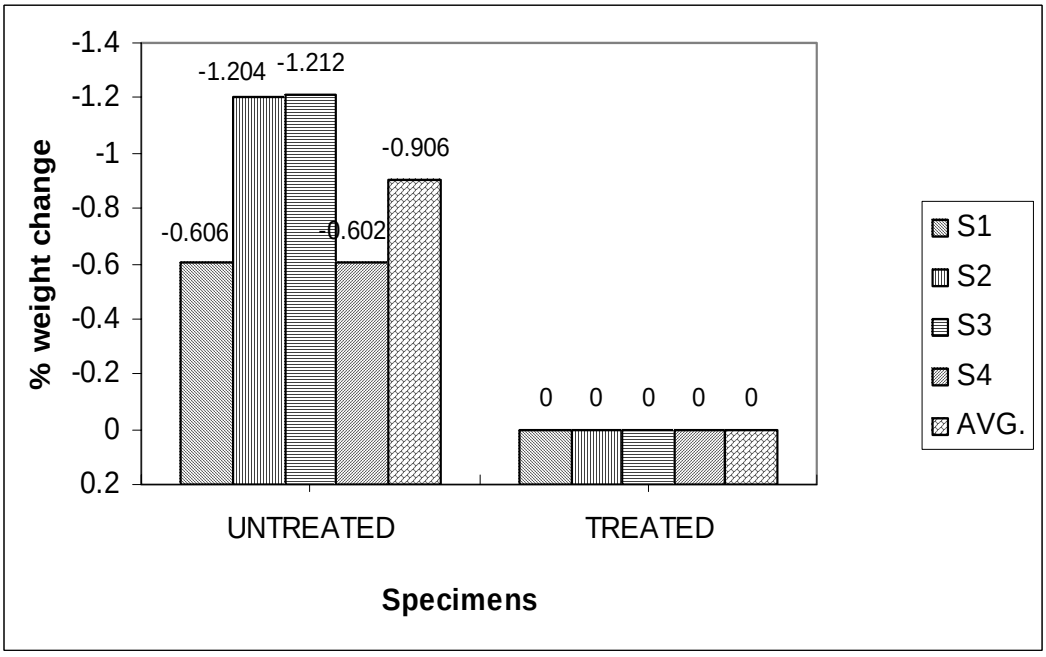

Figure 3.19 % Weight Change of Specimens for 283 and 304 Cycles

3.5 Rapid Chloride Ion Permeability Test Results

The Rapid Chloride Ion Permeability standard test method is performed according to ASTM C 1202-91 and AASHTO T 277-93. The test procedure was discussed in Section 2.13 of Chapter II. The permeability test results are shown in terms of charge passing, measured in coulombs, through a two inch section of concrete specimen. The test was conducted on top two inches of concrete specimens since they were subjected to more environmental action. The age of the test specimens have significant effects on the test results, depending of the type of concrete and curing procedure. Other properties that will affect permeability test results are w/c ratio, air content and aggregate gradation.

The test specimens used for this specimens consists of both cored specimens and laboratory prepared specimens. The cores specimens both treated and untreated were provided by International Chem Crete Inc. The cored specimens were taken form parking lot and were two years old. The laboratory prepared specimens were cast in the material laboratory of UTA along with the other test specimens. The experimental test results for permeability test in cored and laboratory prepared specimens are provided in Tables B-17 and B-18 of Appendix B. The test result for cored specimen's show there is negligible or very low penetration of chloride ion for both treated and untreated specimens. This may be due to age of concrete of cored specimen since the age of the specimen has significant effects on test results. The test result for laboratory prepared specimens show different results from that of cored specimens. The average chloride penetration of treated specimen is just below the 2000 coulombs whereas, for untreated

specimens the chloride ion penetration is around 4000 which is high. In both different kinds of specimens, chloride ion penetrations for untreated specimens are higher than treated specimens. It should be noted that specimens with average chloride penetration less than 2000 coulombs are considered durable [20].

The comparison between treated and untreated specimen of cored and laboratory prepared specimens for chloride ion penetration test are presented in Figure 3.20 and 3.21, respectively.

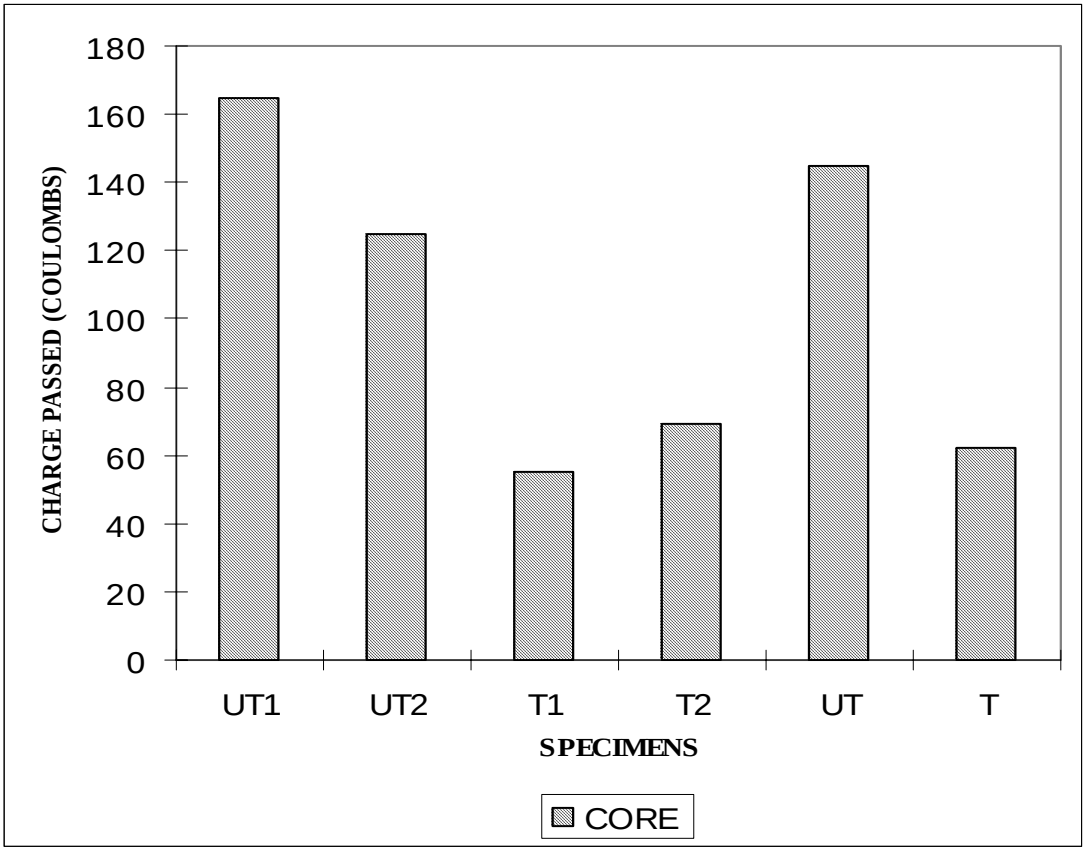

Figure 3.20 Permeability Test Result for Core Specimens

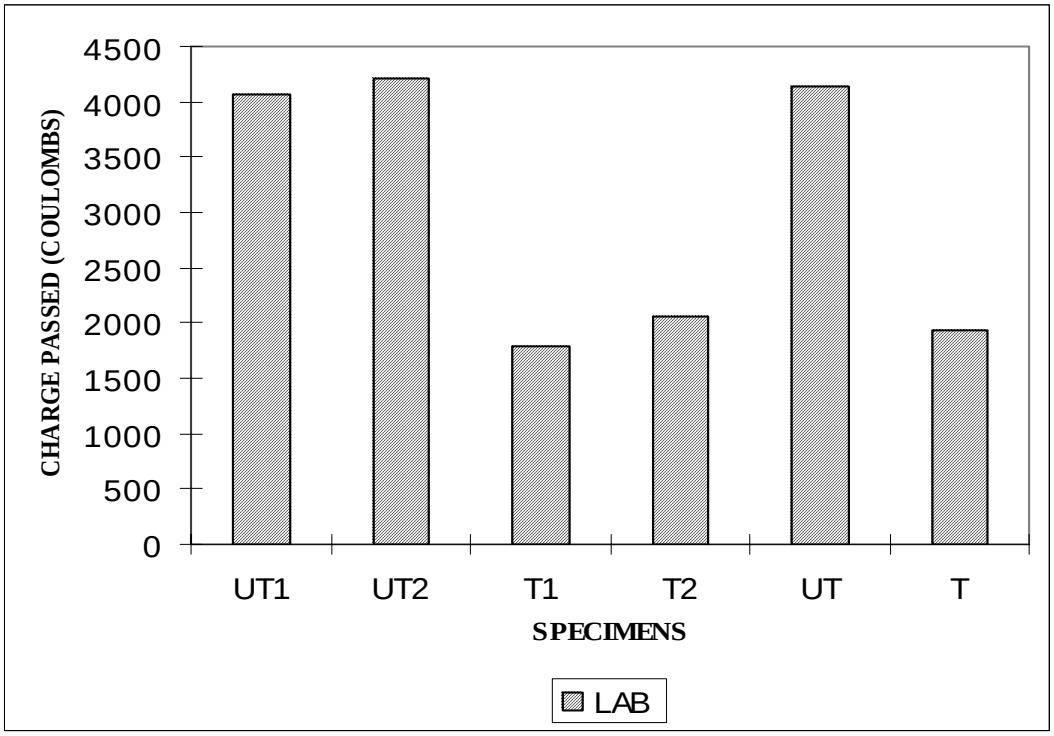

Figure 3.21 Permeability Test Result for laboratory Prepared Specimens

Figures 3.20 and 3.21 present the permeability test result of the top 2 inch layer of cored and laboratory specimens. The top 2 inch layer is important since it is in direct contact with harsh weather conditions of the environment. It can be shown from above figure; the treated specimens perform better than the untreated specimens.

3.7 Petrographic Analysis for Hardened Air Content Test Results

The petrographic analysis was conducted by the procedure explained in Section 2.14 of Chapter II. The petrographic analysis is a test to examine the repeatability of the air void structure in hardened concrete mixes. The analysis breaks down the air void content into entrained and entrapped air voids. The differences between the two air voids are their sizes. Entrained air voids are less than or equal to 0.04 nominal diameter

and entrapped air voids are greater than 0.04 inches in diameter. The test results provide the spacing factor of air voids through the specimens, which are important in freeze-thaw testing. The spacing factor gives the average maximum distance from any point in the cement paste to the edge of the nearest void. The maximum value of the spacing factor for moderate exposure of the concrete is usually taken to be 0.008 inch. The smaller the spacing factor for a test specimen, the greater potential that water will reach an air void where it can expand during freezing conditions without causing stress and failure planes in the concrete. The analysis test results should be comparable but slightly higher than the air content design for the mix. The petrographic analysis test will be more reliable than the lab measured air content. The petrographic analysis is conducted in the same specimens used for the chloride penetration test.

The experimental test results of petrographic analysis for both cored and laboratory prepared specimens are given in Tables B-19 and B-20 of Appendix B, respectively. Results from the Appendix B show that the air-void content and the spacing factor for both treated and untreated specimens, as expected, are nearly same. The air-void content for the cored treated and untreated specimens are low, which is considered not desirable for freeze-thaw condition. The comparison between spacing factor and air void content are presented in Figure 3.22 and Figure 3.23.

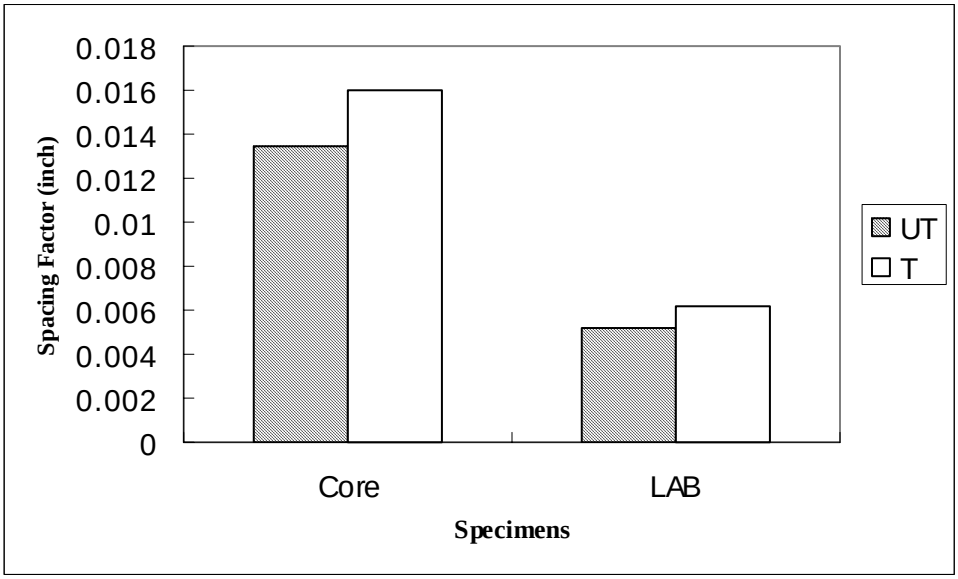

Figure 3.22 Comparison of Spacing Factor

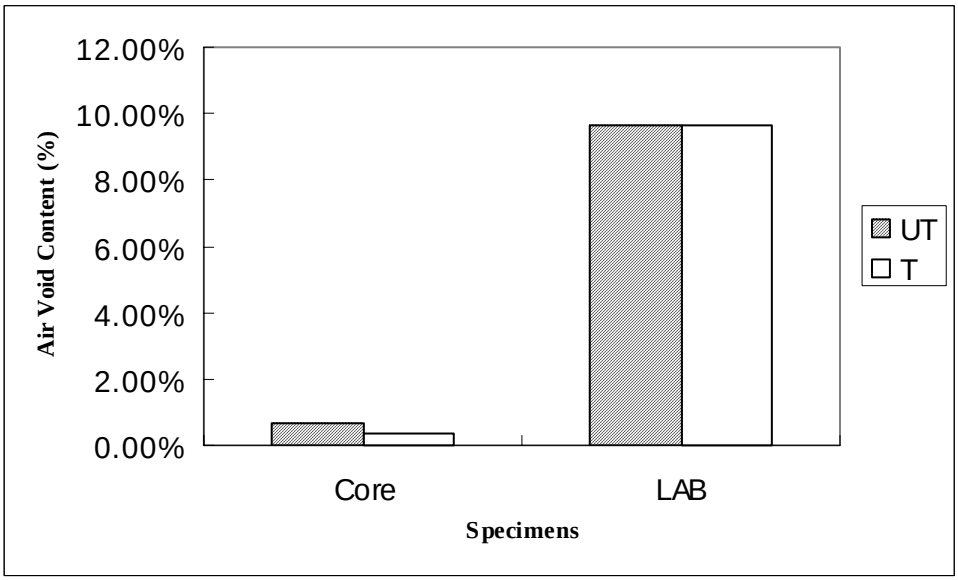

Figure 3.23 Comparison of Air Void Content

Figure 3.22 shows that the spacing factor for the treated and untreated specimens for both cored and laboratory prepared samples are nearly same, which are 0.016 and 0.135 inch, respectively. This is considered to be not desirable for the

concrete with good resistance to freeze-thaw damage. The spacing factor for laboratory prepared treated and untreated specimens are 0.0062 and 0.0052 inch, respectively, which is considered acceptable for the concrete with good resistance to freeze-thaw damage. The smaller the spacing factor is better for freeze-thaw durability. It can be seen from Figure 3.23 that the air void content for the laboratory prepared treated and untreated specimens have the same air void content of 9.6%. This air void content of 9.6% is considered excellent for the concrete with good freeze and thaw resistance.

CHAPTER 4

CONCLUSION AND RECOMMENDATION

4.1 Summary and Conclusion

The objective of this study was to investigate the durability properties of Chem-Crete Pavix (CCP) treated and untreated concrete specimens. This was done by carrying out experimental investigations to study and to evaluate the damaged caused by water in concrete infrastructure with and without special water proofing substance CCP. The experimental investigation includes water absorption, freeze-thaw, chloride ion penetration and petrographic tests

Mix design included the normal mix design used in pavement construction. The mix design was done for expected slump value of 5 inch, air content of 5% and water cement ratio of 0.5. Additional mix design with 0.35 water cement ratio was done for absorption test. Aggregates used in this mix were from Bridgeport pit and Ferris pit, Texas. The entire test was performed in accordance to standard test methods explain in Chapter II. The test results for the mix design can be found in Chapter III.

The average 28-day compressive strength of each mix design used in this project was 3890 psi. The target 28-day compressive strength was 3500 psi. Since the entire specimen tested for the compressive test has a value more than target 3500 psi, the concrete mix design was used for further laboratory testing.

The Texas Department of Transportation (TXDOT) requirement on the flexural strength of concrete is 555 psi or greater on the 28-day. The maximum 28- day flexural strength was 585 psi with average 573 psi. Since the entire specimen tested for flexural test has much more than minimum value of 555 psi by TXDOT, the concrete used in this project was used for further laboratory testing.

One of the key durability properties evaluated in this research study was the Absorption and Air Void test. One of the main objectives of this study was to decrease the water absorption capacity of concrete to reduce the water related deterioration. The average water absorption test result of treated specimen was 2.1% while for untreated specimen was 6.05% for concrete with water cement ratio of 0.5. For the concrete with water cement ratio 0.35, the absorption capacity for treated specimen was 0.89% and untreated specimen was 3.98%. In both mix, the absorption capacity was reduced by more than 50%. The result shows the similarities with the test done by M.M. Al-Zahrani et al. [14], which have the absorption ratio of 0.17%, 1.92%, 6.41%, and 0.70% for different waterproofing material. The test result also shows the significant reduction of permeable pore space in treated specimen.

For the Freeze and Thaw test, optional length change test was performed. The test results show that treated specimen shows better result than untreated specimen. The average percent length change for the treated specimen was 0.039 % compare to the untreated specimen with percent length change of 0.09%. There was no change in weight in the treated specimen while some change in weight was found in all untreated specimen.

The chloride ion penetration test was performed on both cored and laboratory prepared specimens. The cored samples both treated and untreated were provided by International Chem Crete Inc. The test was performed on top 2 inch layer of the concrete specimens since they were subjected to more environmental action. . All tests were done by maintaining the potential difference of 60 volts DC for 6 hours across the ends of the specimens as per ASTM C 1202-91. Test data is collected at five minutes intervals throughout the 6-hour duration of the test. The chloride ion permeability for cored treated specimen was 62 coulombs compare to untreated specimen with value of 145 coulombs. Both of these values are considered very low according to the ASTM standard. The chloride ion permeability for lab prepared treated specimens was 1927 coulombs compare to untreated specimens with value of 4142.5 coulombs. It should be noted that specimens with average chloride penetration less than 2000 coulombs are considered durable [20]. The big difference between the cored and lab prepared specimen may be due to age of concrete of cored specimen since the age of the specimen has significant effects on test results. Although, in both cases the treated specimens performed better than untreated specimen.

For the petrographic test, procedure A, the linear-traverse method was performed. The test was performed on both treated and untreated cored and laboratory specimens. The data collected form this test was used to calculate the air content and various parameters of the air-void system of hardened concrete. The air-void content was 0.37% and 0.67% for cored treated and untreated specimen, respectively, which is considered very low for the concrete with good freeze-thaw resistance. The air-void

content for both laboratory prepared treated and untreated specimens was 9.7%. The spacing factor for cored treated and untreated specimens was 0.016 and 0.0135 inch, respectively. These factor for laboratory prepared treated and untreated specimens were 0.0062 and 0.0052 inch, respectively. The results shows that the air void content and spacing factor for both cored and laboratory prepared specimens are nearly same.

In general, test results showed that the treated concrete specimens performed superior to the untreated specimens. The conclusions of this research are as follows:

1. By the application of waterproofing material on concrete the absorption ratio and permeable pore space is reduce by more than 50% making concrete less permeable.
2. From freeze and thaw tests it was found that deterioration rate of untreated concrete is nearly double of that of treated concrete. There was no change in weight after complete 300 freeze-thaw cycles in treated specimens.
3. Chloride ion penetration test showed the similar result as in the case of other durability test in which treated specimens performed better than untreated one. Overall, it was shown that permeability is reduced significantly by application of waterproofing material.
4. The petrographic test was conducted to measure the actual air void content of the mix design.

4.2 Recommendation

Based on the experimental studies conducted the following recommendations need to be taken in to account in future research:

1. The same experimental program should be performed with different water cement ratio such as 0.35, 0.40, and 0.45 to study performance of waterproofing materials in different strength of concrete.
2. This study was conducted for target air content of 5% for pavement construction. It is recommended to conduct test on concrete with different air content such as 0%, 2%, 4%, and 6% used for different applications to study the effect of air content on waterproofing material treated concrete.
3. More tests should be performed on existing aged cored concrete specimens and controlled concrete laboratory specimens. It is recommended that the laboratory specimens be subjected to long-term field-simulated environment and loading condition.

APPENDIX A

MATERIAL CONSTITUENTS, AGGREGATE TEST RESULTS, MIX DESIGN

MATERIALS

Cement**:**	Type I Portland Cement (meets ASTM C150 specification), supplied by Home Deport, Arlington, Texas.
Coarse Aggregate**:**	Crushed limestone, maximum size 1 inch meeting the ASTM C 33 specifications, supplied by Hanson Aggregates, South Central Region, 1000 N. Mac. Arthur Blvd. Grand Prairie, Texas from the Bridgeport Pit located at Bridgeport, Texas.
Fine Aggregate**:**	#4 Minus Crushed limestone Sand meeting the ASTM C 33 specifications, supplied by Hanson Aggregates, South Central Region, 1000 N. Mac. Arthur Blvd. Grand Prairie, Texas from the Ferris Pit located at Ferris, Texas.
Admixtures**:**	ProAir 260, air entraining admixture meeting the ASTM C 260, and Plastimix 50, water-reducing admixture conforming to the ASTM C 494 Types A and D, manufactured by Pro Mix Technologies, Rockwell, Texas.

TEST RESULTS OF AGGREGATES

Moisture Content

Table A-1 Moisture Content of Fine Aggregate

Pan no.	1	2	Avg.
Wt of pan (A),	329.80	332.80	331.30
Wt of pan + Specimen(B)	1311.50	1341.10	1326.30
Wt of pan + Specimen(After oven drying)(C)	1272.50	1301.00	1286.75
Total moisture content =(B-C)/C x 100	3.06	3.08	3.07

All weights are in gram.

Table A-2 Moisture Content of Coarse Aggregate

Pan no.	1	2	Avg.
Wt of pan (A)	392.00	398.40	398.20
Wt of pan + Specimen(B)	4735.20	4758.70	4746.95
Wt of pan + Specimen(After oven drying)(C)	4727.20	4750	4738.6
Total moisture content =(B-C)/C x 100	0.173	0.183	0.176

All weights are in gram.

Specific Gravity

Table A-3 Specific Gravity of Fine Aggregate

Pan No.		1	2	AVG.
Pan wt.(A)gm		210.1	213.1	211.6
SSD wt.(B)gm		775.9	838.8	807.35
Pycnometer +water (C)gm		1475.1	1475.2	1475.15
Pycnometer +water + Specimen(D)gm		1957.8	1996.6	1977.2
Dry specimen wt.+ pan(E)gm		982.1	1045.4	1013.75
Dry specimen wt.(F) gm=	E-A	772	832.3	802.15
Bulk specific Gravity, SSD =	B/(C+B-D)	2.64632	2.64272	2.6445
Apparent specific Gravity =	E/(C+F-D)	2.66851	2.67707	2.6728
Absorption (%) =	(B-F)/F x100	0.50518	0.78097	0.6431

Table A-4 Specific Gravity of Coarse Aggregate

		1	2	AVG.
Pan wt.(A)		198.1	198	198.05
SSD wt.(B)		1267	1296.7	1281.85
Pycnometer +water (C)		2747.1	2747.1	2747.1
Pycnometer+ water+ Specimen(D)		3546.2	3558.6	3552.4
Dry specimen wt.+ pan(E)		1461.1	1487.8	1474.45
Dry specimen wt.(F)=	E-A	1263	1289.8	1276.4
Bulk specific Gravity, SSD =	B/(C+B-D)	2.70784	2.67251	2.690175
Apparent specific Gravity =	E/(C+F-D)	2.72257	2.69663	2.709602
Absorption (%) =	(B-F)/F x100	0.31671	0.53497	0.425836

Sieve Analysis of Fine Aggregate

Sieve used: - No.200, No.100, No.50, No.30, No.16, No.8 and No.4
Sample weight = 779.6gm

Table A-5 Sieve Analysis of Fine Aggregate

Sieve no.	Weight Retained (g)	Percent Retained	Percent Coarser	Percent Finer
4	1.1	0.14	0.14	99.86
8	3.7	0.47	0.61	99.39
16	11.2	1.43	2.04	97.96
30	70.1	9.00	11.04	88.96
50	349.2	44.80	55.84	44.16
100	271.00	34.76	90.6	9.4
200	66.3	8.50	99.1	0.9
pan	6.5	.83	99.93	0.07
		Cumulative:	259.37	

Fineness modulus =259.37/100
=2.60

Average sieve size = 3rd sieve from the bottom
=No.50 =0.0117in.

Sieve Analysis of Coarse Aggregate

Sieve used: - No8, No.4, 3/8 in, 1/2 in, 3/4 in, 1 in, 1 ½ in
Sample weight = 8473.2gm

Table A-6 Sieve Analysis of Coarse Aggregate

Sieve no.	Weight Retained (g)	Percent Retained	Percent Coarser	Percent Finer
1 ½	0	0	0	0.00
1	466.1	5.50	5.50	94.5
¾	2063.2	24.34	29.84	70.16
½	3718.1	43.88	73.72	26.28
3/8	1309.3	15.45	89.17	10.83
4	812.1	9.59	98.76	1.24
8	63.6	0.75	99.51	0.41
pan	23.7	0.27	99.78	0.22
		Cumulative:	317.28	

Fineness modulus =317.28/100
=3.18=3.20

Number of Specimen

Table A -7 No. of Specimen

Specimen	Number	Test
Cylinder(6 x 12 in)	6	Compression Test
Cylinder(4 x 8 in)	8	Absorption Test
Beam(6 x 6 x 20 in)	6	Flexure Test
Beam (4 x 3 x 11.25in)	8	Freeze and Thaw Test

Mix Design

Mix Design for water cement ratio 0.5

Table A-8 Mix Design for w/c 0.5

INGREDIENTS	lb/yd^3
Water	260
Cement	517
Coarse Aggregate	1850.1
Fine Aggregate	1286.1
Total	3931.1 lb/yd^3

Admixture used for this mixture is 3.0 FL. Ozs/100 cement weight for water reducing and 0.4 FL. Ozs/100 cement weight for air content.

Mix Design for water cement ratio 0.35

Table A-9 Mix Design for water cement ratio 0.35

INGREDIENT	lb/yd^3
WATER	308
CEMENT	843
COARSE AGGREGATE	2050
FINE AGGREGATE	663
TOTAL	3864 lb/yd^3

No admixture was used.

APPENDIX B

EXPERIMENTAL TEST RESULTS

Flexural Test Result

Table B-1 28 days Flexural Test Result (0.5 w/c ratio)

Specimen No.	Maximum Applied load (lbf)	L	Bd^2 (6” x 6”)	MOR (psi)
F-1	7000	18”	$216in^2$	585
F-2	6800	18”	$216in^2$	567
F-3	6800	18”	$216in^2$	567
Average	6867	18	216	573

Table B-2 28 days Flexural Test Result (0.35 w/c ratio)

Specimen No.	Maximum Applied load (lbf)	Bd^2 (6 x 6 in) (in^2)	L (in)	MOR (psi)
1	10423	216	18	868
2	9664	216	18	805
3	10903	216	18	908
Average	10330	216	18	860.33

Compression Test Result

Table B-3 28 days Compression Test Result (0.5 w/c ratio**)**

Specimen no.	Diameter (inch)	Area ($inch^2$)	Maximum Load (lbf)	Compressive strength (psi)
C-1	6	28.287	111,100	3930
C-2	6	28.287	107,900	3816
C-3	6	28.287	110,900	3922
Average	6	28.287	109965.67	3890

Air Void Test Result

Table B-4 Absorption Test Result of Untreated Specimen (w/c ratio 0.35)

	Control 1	Control 2	Control 3	Average
Mass of oven dried sample in air, lb (A)	28.55	28.75	29.35	28.88
Mass of surface dry sample in air after immersion, lb (B)	29.70	29.95	30.45	30.03
*Absorption after immersion, %	4.02	4.17	3.74	3.97

Table B-5 Absorption Test Result of Treated Specimen (w/c ratio 0.35)

	Treated 1	Treated 2	Treated 3	Average
Mass of oven dried sample in air before coating, lb (WA)	29.60	29.55	29.55	29.56
Mass of surface dry sample in air after coating, lb (W1)	29.70	29.60	29.60	29.63
Mass of surface dry sample in air after immersion, lb (W2)	29.95	29.90	29.85	29.9
*Absorption after immersion, %	0.84	1.01	0.84	0.89

Table B-6 Absorption Test Result of Untreated Cylinder (w/c ratio 0.5)

	AT-UTC-1	AT-UTC-2	AT-UTC-3
Mass of oven dried sample in air, lb (A)	7.40	7.45	7.40
Mass of surface dry sample in air after immersion, lb (B)	7.85	7.90	7.90
*Absorption after immersion, %	6.08	6.04	6.75

The average water absorption rate of untreated cylinder specimens is 6.29 %.

Table B-7 Absorption Test Result of Untreated Beam (w/c ratio 0. 5)

	AT-UTB-1	AT-UTB-2	AT-UTB-3
Mass of oven dried sample in air, lb (A)	11.00	10.75	10.85
Mass of surface dry sample in air after immersion, lb (B)	11.65	11.35	11.50
*Absorption after immersion, %	5.90	5.58	5.99

The average water absorption rate of untreated cylinder specimens is 5.82 %.

Table B-8 Absorption Test Result of Treated Cylinder (w/c ratio 0.5)

	AT-TC-1	AT-TC- 2	AT-TC-3
Mass of oven dried sample in air before coating, lb (W_A)	7.40	7.50	7.45
Mass of surface dry sample in air after coating, lb (W_1)	7.55	7.65	7.60
Mass of surface dry sample in air after immersion, lb (W_2)	7.75	7.85	7.80
*Absorption after immersion, %	2.70	2.67	2.68

The average water absorption rate of treated cylinder specimens is 2.68 %.

Table B-9 Absorption Test Result of Treated Sample (w/c ratio 0.5)

	AT-TB-1	AT-TB-2	AT-TB-3
Mass of oven dried sample in air before coating, lb (W_A)	11.10	11.10	10.95
Mass of surface dry sample in air after coating, lb (W_1)	11.30	11.35	11.15
Mass of surface dry sample in air after immersion, lb (W_2)	11.45	11.50	11.35
*Absorption after immersion, %	1.35	1.35	1.82

The average water absorption rate of Treated Beam specimens is 1.50 %.

Table B-10 Complete Air void Test Result (w/c ratio 0.5)

		A	B	C	D	AI	AIMb	BD	BDI	BDIB	AD	VPPS
utb1		11.00	11.65	11.75	6.50	5.91	6.82	2.10	2.24	2.24	2.44	14.29
utb2		10.75	11.35	11.45	6.40	5.58	6.51	2.13	2.27	2.27	2.47	13.86
utb3		10.85	11.50	11.65	6.40	5.99	7.37	2.07	2.22	2.22	2.44	15.24
					average	5.83	6.90	2.10	2.24	2.24	2.45	14.46
utc1		7.40	7.85	7.90	4.40	6.08	6.76	2.11	2.26	2.26	2.47	14.29
utc2		7.45	7.90	7.95	4.45	6.04	6.71	2.13	2.27	2.27	2.48	14.29
utc3		7.40	7.90	7.95	4.40	6.76	7.43	2.08	2.24	2.24	2.47	15.49
					average	6.29	6.97	2.11	2.26	2.26	2.47	14.69
	Wa											
tb1	11.10	11.30	11.45	11.55	6.60	1.35	2.21	2.28	2.33	2.33	2.40	5.05
tb2	11.10	11.35	11.50	11.65	6.50	1.35	2.64	2.20	2.26	2.26	2.34	5.82
tb3	10.95	11.15	11.35	11.45	6.55	1.83	2.69	2.28	2.34	2.34	2.42	6.12
					average	1.51	2.52	2.25	2.31	2.31	2.39	5.66
tb1	7.40	7.55	7.75	7.85	4.45	2.7	3.97	2.22	2.31	2.31	2.44	8.82
tb2	7.45	7.65	7.85	7.90	4.50	2.68	3.27	2.25	2.32	2.32	2.43	7.35
tb3	7.45	7.60	7.80	7.90	4.50	2.68	3.95	2.24	2.32	2.32	2.45	8.82
					average	2.69	3.73	2.24	2.32	2.32	2.44	8.33

Wa= mass of oven dry sample for treated sample.
A= mass of oven dry sample for untreated sample, dry mass of treated sample after coating.
B= saturated mass of sample after immersion
C= saturated wt of a sample after boiling
D= Immersed apparent mass
AI = Absorption after immersion (%)
AIMb= Absorption after immersion and boiling (%)
BD= Bulk density, dry
BDI= Bulk density after immersion
BDIB= bulk density after immersion and boiling
AD= Apparent Density
VPPS= Volume of permeable pore space (%)

Freeze-Thaw Test Result

Table B-11 Freeze and Thaw Test (change in length)

Specimen no	Length of specimen 0 cycle	Length of specimen 33 cycle	Length of specimen 80 cycle	Length of specimen 122 cycle	Length of specimen 172 cycle	Length of specimen 228 cycle	Length of specimen 283 cycle	Length of specimen 304 cycle
UT1	0.1885	0.1894	0.1865	0.1827	0.1815	0.1809	0.1800	0.1797
UT2	0.1385	0.1363	0.1342	0.1332	0.1320	0.1308	0.1298	0.1294
UT3	0.0998	0.0964	0.0946	0.0929	0.0920	0.0908	0.0897	0.0895
UT4	0.1290	0.1299	0.1289	0.1252	0.1234	0.1220	0.1214	0.1212
T1	0.0458	0.0457	0.0448	0.0441	0.0439	0.0431	0.0429	0.0429
T2	0.1385	0.1374	0.1370	0.1364	0.1357	0.1355	0.1354	0.1350
T3	0.0650	0.0635	0.0627	0.0621	0.0615	0.0611	0.0609	0.0608
T4	0.1860	0.1840	0.1836	0.1830	0.1821	0.1817	0.1812	0.1810

Table B-12 Freeze and Thaw Test (change in weight)

Specimen no	Weight of specimen 0 cycle	Weight of specimen 33 cycle	Weight of specimen 80 cycle	Weight of specimen 122 cycle	Weight of specimen 172 cycle	Weight of specimen 228 cycle	Weight of specimen 283 cycle	Weight of specimen 304 cycle
UT1	8.30	8.30	8.30	8.30	8.30	8.25	8.25	8.25
UT2	8.40	8.40	8.40	8.40	8.35	8.30	8.30	8.30
UT3	8.35	8.35	8.35	8.30	8.30	8.30	8.25	8.25
UT4	8.35	8.35	8.35	8.35	8.35	8.35	8.30	8.30
T1	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25
T2	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25
T3	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25
T4	8.30	8.30	8.30	8.30	8.30	8.30	8.30	8.30

Table B-13 Freeze and Thaw Test (%change in length)

no of cycles	%length change(UT)	%length change(T)
0	0.00000	0.00000
33	-0.00950	-0.01175
80	-0.02900	-0.01800
122	-0.05450	-0.02425
172	-0.06725	-0.03025
228	-0.07825	-0.03475
283	-0.08725	-0.03725
304	-0.09000	-0.03900

Table B-14 Freeze and Thaw Test (%change in weight)

no of cycles	% weight change(UT)	%weight change(T)
0	0.00000	0.00000
33	0.00000	0.00000
80	0.00000	0.00000
122	-0.01515	0.00000
172	-0.30300	0.00000
228	-0.60600	0.00000
283	-0.90600	0.00000
304	-0.90600	0.00000

Table B-15 Complete Freeze and Thaw Test Result (%change in length)

specimen	length (0 cycles)	length (33cycles)	%length change(33cycles)	avg
UT1	0.1885	0.1894	0.009	-0.0095
UT2	0.1385	0.1363	-0.022	
UT3	0.0998	0.0964	-0.034	
UT4	0.129	0.1299	0.009	
T1	0.0458	0.0457	-0.001	-0.01175
T2	0.1385	0.1374	-0.011	
T3	0.065	0.0635	-0.015	
T4	0.186	0.184	-0.02	
specimen	length (0 cycles)	length (80cycles)	%length change(80cycles)	avg
UT1	0.1885	0.1865	-0.02	-0.029
UT2	0.1385	0.1342	-0.043	
UT3	0.0998	0.0946	-0.052	
UT4	0.129	0.1289	-0.001	
T1	0.0458	0.0448	-0.01	-0.018
T2	0.1385	0.137	-0.015	
T3	0.065	0.0627	-0.023	
T4	0.186	0.1836	-0.024	
specimen	length (0 cycles)	length (122cycles)	%length change(122cycles)	avg
UT1	0.1885	0.1827	-0.058	-0.0545
UT2	0.1385	0.1332	-0.053	
UT3	0.0998	0.0929	-0.069	
UT4	0.129	0.1252	-0.038	
T1	0.0458	0.0441	-0.017	-0.02425
T2	0.1385	0.1364	-0.021	
T3	0.065	0.0621	-0.029	
T4	0.186	0.183	-0.03	

Table B-15-*continued*

specimen	length (0 cycles)	length (172cycles)	%length change(172cycles)	avg
UT1	0.1885	0.1815	-0.07	-0.06725
UT2	0.1385	0.132	-0.065	
UT3	0.0998	0.092	-0.078	
UT4	0.129	0.1234	-0.056	
T1	0.0458	0.0439	-0.019	-0.03025
T2	0.1385	0.1357	-0.028	
T3	0.065	0.0615	-0.035	
T4	0.186	0.1821	-0.039	
specimen	length (0 cycles)	length (228cycles)	%length change(228cycles)	avg
UT1	0.1885	0.1809	-0.076	-0.07825
UT2	0.1385	0.1308	-0.077	
UT3	0.0998	0.0908	-0.09	
UT4	0.129	0.122	-0.07	
T1	0.0458	0.0431	-0.027	-0.03475
T2	0.1385	0.1355	-0.03	
T3	0.065	0.0611	-0.039	
T4	0.186	0.1817	-0.043	
specimen	length (0 cycles)	length (283cycles)	%length change(283cycles)	avg
UT1	0.1885	0.18	-0.085	-0.08725
UT2	0.1385	0.1298	-0.087	
UT3	0.0998	0.0897	-0.101	
UT4	0.129	0.1214	-0.076	
T1	0.0458	0.0429	-0.029	-0.03725
T2	0.1385	0.1354	-0.031	
T3	0.065	0.0609	-0.041	
T4	0.186	0.1812	-0.048	

Table B-15-*continued*

specimen	length (0 cycles)	length (304 cycles)	%length change(304cycles)	avg
UT1	0.18850	0.17970	-0.08800	-0.09000
UT2	0.13850	0.12940	-0.09100	
UT3	0.09980	0.08950	-0.10300	
UT4	0.12900	0.12120	-0.078000	
				avg
T1	0.04580	0.04290	-0.02900	-0.03900
T2	0.13850	0.13500	-0.03500	
T3	0.06500	0.06080	-0.04200	
T4	0.18600	0.18100	-0.05000	

Table B-16 Complete Freeze and Thaw Test Result (%change in weight)

specimen	length (0 cycles)	length (33cycles)	%length change(33cycles)	avg
UT1	8.30000	8.30000	0.00000	0.00000
UT2	8.40000	8.4000	0.00000	
UT3	8.35000	8.35000	0.00000	
UT4	8.35000	8.35000	0.00000	
T1	8.25000	8.25000	0.00000	0. 00000
T2	8.25000	8.25000	0.00000	
T3	8.25000	8.25000	0.00000	
T4	8.30000	8.30000	0.00000	
specimen	length (0 cycles)	length (80cycles)	%length change(80cycles)	avg
UT1	8.30000	8.30000	0.00000	0.00000
UT2	8.40000	8.40000	0.00000	
UT3	8.35000	8.35000	0.00000	
UT4	8.35000	8.35000	0.00000	
T1	8.25000	8.25000	0.00000	0. 00000
T2	8.25000	8.25000	0.00000	
T3	8.25000	8.25000	0.00000	
T4	8.30000	8.30000	0.00000	
specimen	length (0 cycles)	length (122cycles)	%length change(122cycles)	avg
UT1	8.30000	8.30000	0. 00000	-0.15060
UT2	8.40000	8.40000	0. 00000	
UT3	8.35	8.30000	-0.60240	
UT4	8.35	8.35	0. 00000	
T1	8.25	8.25	0. 00000	0. 00000
T2	8.25	8.25	0. 00000	
T3	8.25	8.25	0. 00000	
T4	8.30000	8.30000	0. 00000	

Table B-16-*continued*

specimen	length (0 cycles)	length (172cycles)	%length change(172cycles)	avg
UT1	8.30000	8.30000	0. 00000	-0.30030
UT2	8.40000	8.35000	-0.59880	
UT3	8.35000	8.30000	-0.60240	
UT4	8.35000	8.35000	0. 00000	
T1	8.25000	8.25000	0. 00000	0. 00000
T2	8.25000	8.25000	0. 00000	
T3	8.25000	8.25000	0. 00000	
T4	8.30000	8.30000	0. 00000	
specimen	length (0 cycles)	length (228cycles)	%length change(228cycles)	avg
UT1	8.30000	8.25000	-0.60606	-0.60332
UT2	8.40000	8.30000	-1.20481	
UT3	8.35000	8.30000	-0.60240	
UT4	8.35000	8.35000	0. 00000	
T1	8.25000	8.25000	0. 00000	0. 00000
T2	8.25000	8.25000	0. 00000	
T3	8.25000	8.25000	0. 00000	
T4	8.30000	8.30000	0. 00000	
specimen	length (0 cycles)	length (283cycles)	%length change(283cycles)	avg
UT1	8.30000	8.25000	-0.60606	-0.90635
UT2	8.40000	8.30000	-1.20481	
UT3	8.35000	8.25000	-1.21212	
UT4	8.35000	8.30000	-0.60240	
T1	8.25000	8.25000	0. 00000	0. 00000
T2	8.25000	8.25000	0. 00000	
T3	8.25000	8.25000	0. 00000	
T4	8.30000	8.30000	0. 00000	

Table B-16-*continued*

specimen	weight (0 cycles)	weight (304 cycles)	% weight change(304)	avg
UT1	8.30000	8.25000	-0.60606	-0.90635
UT2	8.40000	8.30000	-1.20481	
UT3	8.35000	8.25000	-1.21212	
UT4	8.35000	8.30000	-0.60240	
T1	8.25000	8.25000	0.00000	0.00000
T2	8.25000	8.25000	0.00000	
T3	8.25000	8.25000	0.00000	
T4	8.30000	8.30000	0.00000	

Chloride Ion Penetration Test Result

Table B-17 Chloride Ion Penetration Test (Core Specimens)

Sample Number	Chloride ion Permeability(coulombs)
Untreated 1	165
Untreated 2	125
Treated 1	55
Treated 2	69

Table B-18 Chloride Ion Penetration Test (Laboratory Prepared Specimens)

Sample Number	Chloride ion Permeability(coulombs)
Untreated 1	4074
Untreated 2	4211
Treated 1	1790
Treated 2	2064

Petrographic Test Result

Table B-19 Petrographic Test Result of Core Specimens

	Untreated Specimen	Treated Specimen
Air Void Content (Percent)	0.67%	0.37%
Paste Content (Percent)	29%	15.90%
Specific Surface (in^2/in^3)	826	734
Spacing Factor, inches	0.0135	0.016
Magnification	100x	100x

Table B-20 Petrographic Test Result of Laboratory Prepared Specimens

	Untreated Specimen	Treated Specimen
Air Void Content (Percent)	9.67%	9.67%
Paste Content (Percent)	29%	33%
Specific Surface (in^2/in^3)	581	541
Spacing Factor, inches	0.0052	0.0062
Magnification	100x	100x

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BIOGRAPHICAL INFORMATION

Roshan was born on August 15, 1980 in Birganj, Nepal to Sudharshan Bhadur Shakya and Surya Laxmi Shakya. He completed his high school from Gyanjoyti High School, Birganj. He was awarded prestigious Colombo Plan Scholarship for his undergraduate studies. His obtained his Bachelor of Civil Engineering degree from National Institute of Technology, Rourkela, Orrisa, India, one of the famous engineering colleges in India.

After completion of his bachelor's degree, Roshan enrolled at The University of Texas at Arlington, Texas, in a Masters program in Civil Engineering (Structures) under the supervision of Dr. Abolmaali. He did his research on water damage evaluation of concrete infrastructure under the guidance of Dr. Abolmaali. He was awarded Civil Engineering branch scholarship and worked as a Graduate Research Assistant for Dr. Abolmaali. He was an active member of Nepalese Student Association.