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**DRYING SHRINKAGE OF CEMENT PASTES AND
HIGH STRENGTH CONCRETES**

A Thesis

Presented to

The Faculty of the Department of Civil & Environmental Engineering
San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

By

Faranak Mahdavi

May 2004

UMI Number: 1420441

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ABSTRACT

DRYING SHRINKAGE OF CEMENT PASTES AND HIGH STRENGTH CONCRETES

by Faranak Mahdavi

The objective of this study was to determine the influence of admixtures on drying shrinkage and compressive strength of high strength concrete (HSC). Cement paste alone was investigated to remove the effect of aggregate on shrinkage as to the effect of individual admixtures on drying shrinkage of HSC.

This study reveals that the type and amount of admixture are key factors affecting drying shrinkage and compressive strength. The mixtures used showed that most of the drying shrinkage occurs during the first 28 days after mixing.

In this investigation three types of mineral admixtures were used. These are fly ash class F, silica fume, and metakaolin (calcine clay, class N). Also, four types of chemical admixtures produced by either W.R. Grace or Master Builder were used. These are shrinkage reducing admixture, high-range water reducing admixture, low-range water reducing admixture, and a retarder.

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I will always be indebted to my family and friends for their continuous support and encouragement throughout my academic studies and my life. I especially want to thank my parents for providing me with this opportunity.

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Nomenclature

Organizations

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
PCA	Portland Cement Association

Units

lb/cyd	Pounds per Cubic Yard
pcf	Pounds per Cubic Foot
psi	Pounds per Square Inch

Abbreviations

G	Grace
HRWR	High-Range Water Reducer
LRWR	Low-Range Water Reducer
MB	Master Builder
SRA	Shrinkage Reducing Admixture

Symbols

A/cm	Aggregate-to-Cementitious Materials Ratio by Weight
CA/FA	Coarse Aggregate-to-Fine Aggregate Ratio by Weight
E_c	Modulus Property of Concrete, psi
f'_c	Compressive Strength of Concrete at 28-day
w/cm	Water-to-Cementitious Materials Ratio by Weight

Chapter 1

Introduction

1.1 Influence of Admixtures on Drying Shrinkage of Cement Paste and High Strength Concrete

Concrete is a construction material that is extensively used around the world because it can be formed in different shapes and sizes. Concrete can be made durable at a relative low cost. Concrete shrinks when it is subjected to drying environment. Concrete may crack by restraining the shrinkage. Shrinkage cracking is one of the issues need to be dealt with in concrete construction, especially for flat structures such as highway pavements, slabs for parking garages, and walls. Using expensive cement, fiber reinforced concrete, secondary reinforcement, expansion joint, and low water content are some of the ways that can be minimized shrinkage cracking.

In this investigation, the effect of different mineral and chemical admixtures, especially shrinkage reducing admixture (SRA) on the drying shrinkage of concrete, were studied. Using SRA was a principal focus on this study. Drying shrinkage was measured by ASTM C 157, “Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete.”

1.2 Objectives

The main objective of this investigation was to study the effect of chemical and mineral admixtures on drying shrinkage of HSC. The paste was a method to get better understanding for HSC.

1.3 Scope

Eighty-one different cement paste mixes were prepared. All cement paste mixes were made with ASTM Type II cement with 0.33 w/cm ratio. Thirty-four concrete mixes were prepared with ASTM Type II cement, w/cm of 0.33 and 0.34.

1.4 Thesis Outline

This thesis consists of five chapters. Chapter 1 describes objectives, scope and also the outline of the research. Chapter 2 contains a review of shrinkage of HSC. Chapter 3 describes the effect of chemical and mineral admixtures on drying shrinkage of cement paste. Chapter 4 contains the effect of chemical and mineral admixtures on drying shrinkage and compressive strength of HSC. Conclusions and future recommendations are described in Chapter 5.

Chapter 2

Review of Shrinkage of HSC

2.1 Introduction

Shrinkage, a volume reduction, is a characteristic of concrete. Drying Shrinkage is a shrinkage that takes place after hardening and is a result of moisture loss. Shrinkage Reducing Admixtures, SRA, were developed to affect this type of shrinkage, and is the subject of this study. There are several types of shrinkage Plastic Shrinkage, Drying Shrinkage, Thermal Contraction, Autogenous Shrinkage, and Carbonation Shrinkage.⁽¹⁾

Plastic shrinkage is the rapid evaporation of water from the surface of the concrete while the underlying plastic concrete remains at the same volume. Drying Shrinkage is the moisture loss after concrete hardens. Thermal Contraction is the change of the volume of the concrete because of the change of the temperature during the hydration process. Autogenous Shrinkage is the chemical reactions that occur during cement hydration. Carbonation Shrinkage occurs when the calcium hydroxide in the hardened matrix reacts chemically with the carbon dioxide in the atmosphere.

Drying shrinkage is a result of loss of moisture from concrete; therefore, drying shrinkage is inevitable unless leave the concrete in water or in an environment with 100 % humidity. Since drying shrinkage is a serious problem in concrete, admixtures have been developed to reduce this volume change.

Several factors influence the drying shrinkage of the concrete: water-to-cement ratio, composition and fineness of cement, type, amount, and gradation of aggregate, moisture, temperature, admixtures, and size and shape of specimen.

The role of water content and coarse aggregate are very significant in the drying shrinkage because both have an effect to minimize the paste content. Hard, rigid aggregate such as dolomite, limestone, quartz, granite, feldspar are difficult to compress, so they should be used whenever possible to reduce drying shrinkage.

HSC is defined by the American Concrete Institute (ACI) as a concrete with a compressive strength greater than 6000 psi (42 MPa).⁽²⁾ HSC is an important building material for the design of concrete structures. A structure with HSC requires less volume of concrete than a structure with normal-strength concrete. HSC requires less reinforcement and formwork.

High-strength concrete (HSC) shows higher strength, toughness, durability, energy absorption, stiffness, and ductility than normal concrete. It is usually made with relatively low w/cm ratio (about 0.25-0.32).

“Another term for HSC is high performance concrete. According to the Portland Cement Association, HSC is a form of high performance concrete, but the inverse is not necessarily true. High-performance concrete requires special mixing, placing, and curing practices because of its constituents.”

Adding admixtures such as superplasticizers, fly ash, silica fume, and SRA may also improved the performance of the concrete.

2.2 Materials and Proportioning

HSC consists of the same constituents as normal-strength concrete: coarse and fine aggregate, cement, water, and admixtures.⁽³⁾ The strength of the concrete depends upon many factors. Water-to-cement ratio is one of the most important factors affecting the strength of the concrete.

One difference between high-strength concrete and normal-strength concrete is that, in high-strength concrete the entrapped air is decreased. The size and shape of the aggregates are also key factors to increase the strength of the concrete.

The addition of high range water reducing admixture may be necessary to improve the workability at low water-to-cement ratios.

2.2.1 Cement

Four compounds are the major constituents of cement: Tricalcium silicate, Dicalcium silicate, Tricalcium aluminate, and Tetra calcium aluminoferrite. The silicates, C_3S and C_2S , are the most important compounds for the strength of hydrated cement paste.

Hydration of cement is a chemical process: therefore the rate of hydration depends on the fineness of cement particles.

2.2.2 Cement Paste

It is necessary to determine the water content for cement to produce a paste of standard consistence.

The Abrams rule implies that the quality of the cement paste controls the strength of the concrete; the paste quantity has less effect. However, aggregate do play some role. For instance, two comparable concretes with the same w/cm, the strength of concrete with higher cement content is lower.⁽⁴⁾

2.2.3 Aggregates

Almost three quarters of the volume of concrete is occupied by aggregate. Aggregate not only can limit the strength of concrete but also can affect the durability and structural performance of the concrete. It is economical to use a mix with as much aggregate and as little cement as possible, but it cannot obtain the desirable properties of concrete.

Concrete is made with aggregate particles covering a range size between 3/8 in. to above 5 in. (10 to 125 mm). The use of aggregates 3/8-3/4 in. (10-20 mm) is sufficient for HSC. The shape and surface texture of the aggregate are important in the hardened concrete. Mixing water requirements increase as void content of the aggregate increases because of changes in aggregate shape and texture. The strength of the aggregate and the bond between aggregate and cement play an important role in the compressive strength of the concrete. It is important to use hard and strong coarse aggregates such as quartzite, feldspar, dolomite, limestone, granite, or fine-grained traprock because they do not break down and produce fines during mixing.

Research shows using coarse aggregate such as diabase and limestone produce concrete with higher strength and elastic modulus than those using granite and river gravel.⁽⁵⁾

Fine aggregate has a larger surface area than coarse aggregate; therefore, it has more effect on the amount of water required and the properties of the paste. The bond of the paste to fine aggregate is less critical than the bond of the paste to coarse aggregate because of large surface area of fine aggregate. Coarse sand with a fineness modulus of about 3.0 will produce the best workability and highest compressive strength.

Coarse aggregate occupies the largest volume in a concrete mixture. The amount of the coarse aggregate in a concrete mixture depends on the amount of fine aggregate. Concrete should be proportioned so that paste can cover all the aggregates and the voids between the particles.

2.2.4 Mixing Water

The quality of water is important because impurities in the water may interfere with the setting of the cement, may adversely affect the strength of the concrete or cause staining of its surface, and may also lead to corrosion of the reinforcement.

2.2.5 Chemical Admixtures

The benefits of chemical admixtures in shrinkage have mandated their use. It is common to use shrinkage reducing admixture with water reducing admixture.

Shrinkage reducing admixture was developed in Japan by Nihon Cement Co., Ltd, in 1982. In 1985, Goto et al. were awarded a patent for this invention in U.S.⁽⁶⁾ The main component of the SRA developed by Goto et al. is polyoxyalkylene alkyl ether, a lower alcohol alkyleneoxide adduct.

Shrinkage reducing admixture reducing cracks caused by the drying shrinkage. This admixture reduces capillary tension and tensile forces within concrete pores as concrete dries. In addition reducing the drying shrinkage, SRA affect other hardened concrete properties as well.

Shrinkage reducing admixture is compatible with all conventional air entraining agents, water reducers, superplasticizers, set retarders, accelerators, silica fume admixtures. Precaution should be taken to avoid mixing SRA with other admixtures before they enter the concrete.

In general, SRA reduces drying shrinkage, drying shrinkage cracking, and improves aesthetics, watertightness, and durability.

2.2.6 Mineral Admixtures

Mineral admixtures are added to concrete to improve hardened properties of the concrete. Mineral admixtures are classified as: pozzolans, pozzolanic, and cementitious materials, nominally inert materials and cementitious materials. One important mineral admixture in the HSC is pozzolans. Pozzolans is defined in ASTM Standard Definition C219 as a siliceous or siliceous and aluminous material, which has little or no cementitious value.

As cement hydrates, calcium hydroxide reacts with water at ordinary temperature, and causes pozzolans to form compounds possessing cementitious properties.⁽⁷⁾ Common types of pozzolans are fly ash, silica fume, calcine clay such as metakaolin, slag and natural pozzolans such as volcanic ash.

Fly ash is a by-product of the combustion of pulverized coal in thermal power plants. Fly ash because of its pozzolanic and cementitious properties improves durability and strength of the concrete when used with Portland cement. Fly ash particles are spherical, so they decrease the water demand for the mix and increase the compressive strength. Fly ash with higher fineness and higher pozzolanic index produce higher compressive strength and modulus of elasticity.

Fly ash can be used as a replacement of percentage of cement, so it can increase the strength of the concrete because of its silica, alumina and iron rich composition. The advantages of fly ash: improves workability, reduces water demand, volume change, segregation and bleeding, lowers heat of hydration, improves effectiveness of water reducing admixtures and resistance to sulfates, increase ultimate compressive strength, while some of disadvantages of fly ash: lower early strength, finishing difficulties, reduced surface abrasion resistance. Use of fly ash with superplasticizers is a mandatory requirement to produce HSC.

Silica fume is composed of fine, solid, glassy spheres of silicon dioxide. Silica fume reduces permeability and improves durability. Silica fume as fly ash can be substituted for a percentage of Portland cement and by reducing water content of the mix increases the strength of the concrete. Silica fume increase the strength of the concrete

by increasing the strength of cement paste. However, some evidences show silica fume strengthens the concrete by strengthening the bond between cement paste and aggregate. Recently, silica fume along with superplasticizers has been used to produce concrete with higher strength and durability.⁽⁸⁾

Metakaolin is calcine clay. Kaolin is a fine, white, clay mineral that has been used in the manufacture of porcelain. Metakaolin is a supplementary cementing material like fly ash and silica fume.

2.3 Mixing and Placing

2.3.1 Mixing

The procedure for mixing normal strength concrete is similar to that required for HSC and is described by ACI 211.1. The basic consideration for proportioning HSC required to produce concrete with desired plastic properties (workability, finishability, etc.) and hardened properties (strength, durability, etc.) at the low cost.

Mixing HSC is more difficult than normal concrete because of high cement contents, low water contents, and the absence of large coarse aggregate. In general, two types of mixers can be utilized for mixing concrete: drum mixers and turbine mixers.

2.3.2 Placing

HSC may require more care in placing as normal concrete. Preparations to transport, place, consolidate, and finish of HSC may need to be done quickly because of

low workability of HSC. After concrete is placed in forms, it must be immediately vibrated. Vibration removes entrained air in the mix.

2.3.3 Curing

Concrete must be properly cured for an adequate time in order to potential strength and durability of concrete completely develop. The chemical reaction between cement and water or “hydration” is responsible for the strength-producing properties of cement paste. Time, temperature, and moisture condition affect hydration. In the beginning hydration occurs rapidly, but with time hydration happens more and more slowly and stops when the relative humidity of the concrete drops 80%. The strength of HSC improves for a longer period of time because relative humidity decreases more slowly in concrete with lower w/cm.

HSC is a concrete with w/cm less than 0.4 required for hydration of cement.⁽⁹⁾ In order to prevent this, water-curing method is suggested during the first 24 hours because this method of curing provides the additional water needed. Burlap, cotton mats, rugs will help to hold water on the surface of the concrete.

In order to hydration takes place completely in high-strength concrete saturated normal-weight aggregates should be used. This produces higher compressive strength in concretes with low water-to-cement ratio.

2.3.4 Testing

Standard ASTM should be used for sampling, molding, curing, and testing of cylinders.^{(10),(11),(12)}

Specimens were cast in reusable steel molds. The top of the molds should be finished very smooth and level. They should be covered with a plastic paper in order to be protected from loss of moisture.

Cylinders should be capped with a plastic cap, and leave them in a moist room to protect them from loss of moisture and strength. Cylinders were provided for this study was 4 x 8-in. (100 x 200-mm) and 6 x 12-in. (150 x 300-mm) Malhotra in 1976 has done some research on the effect of specimen size, and he found out 4 x 8-in. (100 x 200-mm) cylinders are acceptable to substitute for 6 x 12-in. cylinders. Even though testing smaller cylinders give slightly higher compressive strengths. Factors that affect measured compressive strength are specimen size and aspect ratio, preparation of the ends of the specimens, and size of the test machine's bearing block. Smaller cylinders have more advantages: easier to handle and transport, occupy less space, economy, and require smaller testing machine.

Testing machine should be adjusted before the test. Cylinders should be centered and a protective cage should be used to surround the cylinders. The operator should wear goggles, safety glasses, earplugs, or a face shield.

The cylinders should break to failure. After each test machine-bearing surface, the capping materials should be checked.

2.4 Properties

Compressive strength is the most important design property of the concrete. Tensile strength, modulus of rupture, and elastic modulus of the concrete are related to compressive strength of the concrete. Shrinkage and creep are time dependent property of the concrete.

2.4.1 Compressive Strength

HSC has been defined as a concrete having a compressive strength in the range from 6000 psi to 15000 psi (42-100 MPa). High-performance concrete is another term for HSC. High-performance concrete has to meet special performance requirements which are easier placing and compaction, high early-age strengths and superior long-term mechanical properties, volume stability with increased resistance to deformation and cracking, enhanced durability, and increased resistance to chemical attack, cyclic freezing and thawing, high temperatures.

A minimum of two specimens should be tested for each age according to ASTM C 157. Testing HSC for compressive strength puts into doubt a certain number of concrete testing practices. Most concrete laboratories are equipped with loading capacity machines inadequate for testing 6 x 12-in. (150 x 300-mm) cylinders, thus limiting HSC specimens to 4 x 8-in. (100 x 200-mm) size. Therefore, HSC compressive strength values in 4 x 8-in. cylinders are greater by 5%.⁽¹³⁾

Building codes such as the ACI 318 - 02 provided guidelines for concrete mixtures to improve durability of concrete structures in aggressive environments. For

structures that would be exposed to chlorides or sulfates, the code recommends minimum cement contents, limits the water cementitious material ratio and the use of pozzolans and ground-granulated blast-furnace slag.

2.4.2 Modulus of Elasticity

One of the most important elastic properties of the concrete is modulus of elasticity. The modulus of elasticity E_c is the ratio normal stress to strain. The modulus of elasticity is useful to measure the stiffness or resistance of the material to deformation. Elastic modulus of concrete is proportional to the 0.5 power of the cylinder compressive strength was found to be accurate for the elastic modulus at ages 12 hr. and above for all concrete mixes investigate. The empirical relationship between elastic modulus E_c and compressive strength f_c' can be expressed as:⁽¹⁴⁾

$$E_c = 40,000 * (f_c')^{0.5} + 1.0 \times 10^6 \text{ psi}$$

The elastic modulus of high-performance concrete is strongly influenced by the elastic properties of coarse aggregates. The good bond at interface of the coarse aggregate and mortar results in a composite material whose components are cement paste and coarse aggregate.

Chapter 3

Effect of Admixtures on Cement Paste

3.1 Introduction

This chapter describes the effects of various types of admixtures on the drying shrinkage of cement paste, so that a better understanding of shrinkage of concrete can be obtained in the next chapter. The cement pastes included in this study contain cement, water, and mineral and chemical admixtures. Three types of mineral admixtures were used. These are fly ash class F, silica fume, and metakaolin (calcine clay, class N). Also four types of chemical admixtures produced by either Master Builder or W.R. Grace were utilized. These are shrinkage reducing admixture, high-range water-reducing admixture, low-range water reducing admixture, and a retarder. Tests were conducted to evaluate shrinkage, expansion of the cement paste with different admixtures according to ASTM C 157.

3.2 Properties of Cement Paste Constituents

3.2.1 Cement

ASTM type II Portland cement was used in this study. The cement meets ASTM C 150 specifications. Chemical compositions and physical properties of the cement are given in Table 3-1.

3.2.2 Admixtures

The admixtures used in this study were divided in two categories:

1) Mineral Admixtures

- A. Fly Ash class F- normally produced from burning anthracite bituminous coal and this class fly ash has pozzolanic properties. The chemical and physical compositions of the fly ash are given in Table 3-2 in accordance to ASTM C 618.
- B. Silica Fume- very fine non-crystalline silica (SiO_2) produced by electric arc furnaces as a by-product of the production of metallic silicon or ferrosilicon alloys. The chemical composition and physical properties of the silica fume are given in Table 3-3.
- C. Metakaolin (calcine clay, class N)- is calcined kaolin clay with approximately 1.5% loss on ignition, and contains less than 1% quartz. The chemical and physical compositions of the metakaolin are given in Table 3-4.

2) Chemical admixtures

W.R. Grace Products:

- A. SRA-G (Eclipse) is a shrinkage-reducing admixture no ASTM specifications available at this time.
- B. HRWR-G (ADVA-100, superplasticizer) is high-range water-reducing admixture. It is an admixture that reduces the quantity of mixing water required to produce concrete of a given consistency by approximately 12% in accordance to ASTM C 494-90.
- C. LRWR-G (WRAD-64) is a low-range water-reducing admixture. It is an admixture that reduces the quantity of mixing water required to produce concrete of a given consistency. It meets ASTM C 494-90.

Master Builder Products:

- D. SRA-MB (Tetraguard-AS20) is a shrinkage-reducing admixture, no ASTM specifications available at this time. It is an admixture that reduces the drying shrinkage.
- E. HRWR-MB (Rheobuild-3000 FC) is high-range water-reducing admixture, meets the specification of ASTM C 494 Type A and F.
- F. Retarder-MB (Delvo Stabilizer, hydration control admixture) is a retarding admixture, meets the specification of ASTM C 494 Type B and D. It is an admixture that retards the setting time of concrete.

3.3 Mix Design

A total of eighty-one cement paste mixes were made in this study to investigate the effect of different types of admixtures. The cement pastes were made with type II Portland cement and have water-to-cementitious material ratio (w/cm) of 0.33. Table 3-5 and Table 3-6 describe the mix compositions and proportions.

3.4 Mixing Procedure

All cement pastes were mixed at room temperature using a three-speed kitchen mixer. The sequence of mixing began with adding mineral admixtures to the cement, next the chemical admixtures, and then the tap water. All mixtures were mixed for three minutes.

Two cement paste prisms with dimensions 1 x 1 x 11 ¼ -in. (25 x 25 x 285-mm) and one 2 x 4-in. (50 x 100-mm) cylinder were prepared for each mix in accordance to ASTM C157.

The cement paste prisms were left to cure for 24 hours at room temperature while they were covered with a plastic sheet. The specimens were then demolded and initial reading was taken by using the length changes measurement device (comparator) in accordance to ASTM C 490. The specimens were placed in water in a 100% humidity room for six days and a second reading was then taken.

The specimens were then placed in a controlled room temperature of

73.4° ± 3°F (23° ± 1.7°C) with a relative humidity of 50% ± 4%. Shrinkage reading was taken at different time intervals up to 180 days. Shrinkage calculations were determined in accordance to ASTM C 157.

3.5 Test Results and Discussion

3.5.1 Shrinkage

Shrinkage data versus age are plotted and tabulated in Appendix I and Appendix II. Shrinkage data versus age up to 180 days for cement pastes with 0.33 w/cm ratios with the initial reading taken after seven days are plotted in Appendix I (one day in mold and six days in water). Shrinkage data and expansion versus age up to 180 days for cement pastes with 0.33 w/cm ratios with the initial reading taken after one day are plotted in Appendix II.

The data and graphs described in this chapter are from the results of Appendix I. The effect of different admixtures on the shrinkage of cement paste is shown in Figures 3-1 through 3-20.

Figure 3-1 shows the effect of adding HRWR-G (ADVA-100) at dosages varying from 0% to 0.8% with 0.33 w/cm ratio. The graph indicates that increasing dosages of HRWR-G reduces drying shrinkage. In general, HRWR-G at a dosage of 0.8% reduces drying shrinkage by 18% at 180 days.

Figure 3-2 shows the effect of SRA-G (Eclipse) at different dosages including 0%, 0.5%, 1.5%, and 2.5% with 0.33 w/cm ratio. It can be observed that increasing dosages of SRA-G decreases the drying shrinkage. SRA-G at a dosage of 2.5% decreases the drying

shrinkage by 31% at 180 days. Furthermore, addition of SRA-G from 1.5% to 2.5% does not significantly affect the drying shrinkage.

Figure 3-3 depicts the effect of different dosages of SRA-G (Eclipse) with 0.4% HRWR-G and 0.33 w/cm ratio. It can be observed that the addition of 0.4% HRWR-G to a dosage of 2.5% SRA-G reduces the drying shrinkage by 32% at 180 days.

Figure 3-4 illustrates the effect of LRWR-G (WRAD-64) at different dosages from 0% to 0.3% with 0.33 w/cm ratio. It can be observed that adding LRWR-G up to 0.3% does not affect the drying shrinkage.

Figure 3-5 shows the effect of different dosages of LRWR-G with 0.4% HRWR-G and 0.33 w/cm ratio. The Figure shows that adding 0.4% HRWR-G to different dosages of LRWR-G (0% to 0.3%) has no significant effect on the drying shrinkage.

Figure 3-6 shows the effect of different dosages of SRA-G with 0.4% HRWR-G, 0.2% LRWR-G and 0.33 w/cm ratio. It can be observed that at a dosage of 2.5% SRA-G with HRWR-G and LRWR-G decreases the drying shrinkage by 45% at 180 days. Furthermore, addition of SRA-G from 1.5% to 2.5% has no significant effect on the drying shrinkage.

Figure 3-7 shows the effect of metakaolin replaced by total weight of cement at different percentage 0%, 10%, 20%, and 30% with 0.2% HRWR-G and 0.33 w/cm ratio. Increasing dosage of metakaolin from 0% to 30% has no significant effect on the drying shrinkage.

Figure 3-8 depicts the effect of silica fume replaced by total weight of cement at different percentage 0%, 10%, 20%, and 30% with 0.2% HRWR-G and 0.33 w/cm ratio. It

can be observed that increasing silica fume at dosage of 30% increases the drying shrinkage by 39% at 180 days.

Figure 3-9 shows the effect of fly ash replaced by total weight of cement at different percentage 0%, 20%, 25%, 30%, and 35% with 0.2% HRWR-G and 0.33 w/cm ratio. Increasing dosages of fly ash from 0% to 35% has no effect on the drying shrinkage.

Figure 3-10 shows the effect of fly ash replaced by total weight of cement at different percentage 0%, 20%, 25%, 30%, and 35% with 5% metakaolin, 0.2% HRWR-G and 0.33 w/cm ratio. The Figure shows that increasing dosage of fly ash from 0% to 35% does not affect the drying shrinkage.

Figure 3-11 shows the effect of fly ash replaced by total weight of cement at different percentage 0%, 20%, 25%, 30%, and 35% with 5% silica fume, 0.2% HRWR-G and 0.33 w/cm ratio. The result shows increasing dosage of fly ash from 0% to 35% does not affect the drying shrinkage.

Figure 3-12 shows the effect of fly ash replaced by total weight of cement at different percentage 0%, 20%, 25%, 30%, and 35% with 5% metakaolin, 0.2% HRWR-G, 1% SRA-G and 0.33 w/cm ratio. It can be observed that increasing fly ash from 0% to 35% does not affect drying shrinkage. When comparing Figure 3-12 to Figure 3-10 adding a dosage of 1% SRA-G reduces the drying shrinkage by 16% at 180 days.

Figure 3-13 shows the effect of fly ash replaced by total weight of cement paste at different percentage 0%, 20%, 25%, 30%, and 35% with 5% silica fume, 0.2% HRWR-G, 2.5% SRA-G and 0.33 w/cm ratio. It can be observed that increasing fly ash from 0% to

35% does not affect drying shrinkage. When comparing Figure 3-13 to Figure 3-11 adding a dosage of 2.5% SRA-G reduces the drying shrinkage by 31% at 180 days.

Figure 3-14 shows the effect of adding HRWR-MB at dosages varying from 0% to 1% with 0.33 w/cm ratio. The graph shows increasing different dosages of HRWR-MB does not affect the drying shrinkage at all. Comparison of Figure 3-14 with Figure 3-1 shows that HRWR-MB does not affect drying shrinkage while HRWR-G reduces the drying shrinkage.

Figure 3-15 shows the effect of SRA-MB at different dosages including 0%, 0.5%, 1.5%, and 2.5% with 0.33 w/cm ratio. It can be observed that adding SRA-MB at dosage of 2.5% reduces the drying shrinkage by 40% at 180 days. Furthermore, addition of SRA-MB from 1.5% to 2.5% has no significant effect on the drying shrinkage.

Figure 3-16 shows the effect of different dosages of SRA-MB with 0.6% HRWR-MB and 0.33 w/cm ratio. The graph shows at a dosage of 2.5% SRA-MB the drying shrinkage reduces by 40% at 180 days. In general, the addition of HRWR-MB to a mix with different dosages of SRA-MB from 0.5% to 2.5% has no effect on the drying shrinkage.

Figure 3-17 shows the effect of different w/cm ratios with 20% fly ash, and 5% metakaolin. The graph shows that increasing w/cm ratios from 0.40 to 0.60 increases the drying shrinkage by 43% at 180 days.

Figure 3-18 shows the effect of different w/cm ratios with 20% fly ash, and 5% silica fume. The graph shows increasing w/cm ratios from 0.40 to 0.60 increases the drying shrinkage by 41% at 180 days

Figure 3-19 shows the effect of different dosages of delvo stabilizer with 0.33 w/cm ratio. It can be observed that increasing dosage of delvo stabilizer from 0% to 0.2% does not affect the drying shrinkage.

Figure 3-20 shows the effect of different dosages of SRA-G with 0.65 and 0.33 w/cm. The figure shows that SRA-G with 0.65 w/cm ratio reduces drying shrinkage by 15% at 180 days; however, SRA-G with 0.33 w/cm reduces drying shrinkage by 35% at 180 days.

3.6 Summary

The purpose of this study was to determine the effect of mineral and chemical admixtures on drying shrinkage of cement paste mixes.

1. HRWR-G at a dosage of 0.8% reduces drying shrinkage by 18% at 180 days.
2. SRA-G at a dosage of 2.5% reduces drying shrinkage by 31% at 180 days; however, addition of SRA-G from 1.5 % to 2.5 % has no significant effect on drying shrinkage.
3. Different dosages of LRWR-G 0%, 0.1%, 0.2%, and 0.3% do not affect drying shrinkage.
4. SRA-G at a dosage of 2.5% with 0.4% HRWR-G reduces drying shrinkage by 32% at 180 days.
5. Different dosages of LRWR-G 0%, 0.1%, 0.2%, and 0.3% with 0.4% HRWR-G has no significant effect on drying shrinkage.
6. SRA-G at a dosage of 2.5% with 0.4% HRWR-G and 0.2% LRWR-G decrease drying shrinkage by 45% at 180 days.
7. Metakaolin replaced by total weight of cement at different percentage 0%, 10%, 20%, and 30% do not affect drying shrinkage.
8. Fly ash replaced by total weight of cement at different percentage 0%, 20%, 25%, 30%, and 35% do not affect drying shrinkage.
9. Silica fume replaced by total weight of cement at different percentage 0%, 10%, 20%, and 30% increase drying shrinkage by 39% at 180 days.

10. Fly ash replaced by total weight of cement at different percentage 0%, 20%, 25%, 30%, and 35% with 5% metakaolin and 0.2% HRWR-G do not affect drying shrinkage.
11. Fly ash replaced by total weight of cement at different percentage 0%, 20%, 25%, 30%, and 35% with 5% silica fume and 0.2% HRWR-G do not affect drying shrinkage.
12. The addition of 1% SRA-G for cement paste with different fly ash content varying from 0% to 35% with 5% metakaolin and 0.2% HRWR-G reduces the drying shrinkage by 16% at 180 days.
13. The addition of 2.5% SRA-G for cement paste with different fly ash content varying from 0% to 35% with 5% silica fume and 0.2% HRWR-G reduces the drying shrinkage by 31% at 180 days.
14. Different dosages of HRWR-MB of 0%, 0.2%, 0.4%, 0.6%, and 1% do not affect drying shrinkage.
15. SRA-MB at a dosage of 2.5% reduces drying shrinkage by 40% at 180 days; however, addition of SRA-MB from 1.5% to 2.5% has no significant effect on drying shrinkage.
16. SRA-MB at a dosage of 2.5% with 0.6% HRWR-MB decreases drying shrinkage by 40% at 180 days.
17. Increasing the w/cm ratio 0.40, 0.45, 0.50, 0.55, and 0.60 with 5% metakaolin, 20% fly ash increases drying shrinkage by 43% at 180 days.

18. Increasing w/cm ratio 0.40, 0.45, 0.50, 0.55, and 0.60 with 5% silica fume, 20% fly ash increases drying shrinkage by 41% at 180 days.
19. Different dosages of delvo stabilizer (retarder) of 0.1% and 0.2% do not affect drying shrinkage.
20. The addition 0.5% SRA-G to a mix with 0.33 w/cm ratio reduces drying shrinkage by 35% at 180 days, also the addition of 0.5% SRA-G to a mix with 0.65 w/cm ratio reduces drying shrinkage by 15% at 180 days.

Table 3-1: Chemical Compositions and Physical Properties of Type II Portland Cement

Chemical Composition %	Type II cement	ASTM C 150 Specifications for Type I cement	ASTM C 150 Specifications for Type II cement
Silicon Dioxide (SiO ₂)	21.73	----	20.0 min
Aluminum Oxide (Al ₂ O ₃)	4.12	----	6.0 max
Ferric Oxide (Fe ₂ O ₃)	3.48	----	6.0 max
Calcium Oxide (CaO)	63.75	----	----
Magnesium Oxide (MgO)	1.72	6.0 max	6.0 max
Sulfur Trioxide (SO ₃)	2.59	3.0 max	3.0 max
Loss on ignition	1.33	3.0 max	3.0 max
Sodium Oxide (Na ₂ O)	0.31	----	----
Potassium Oxide (K ₂ O)	0.44	----	----
Equivalent Alkalies (Na ₂ O+ 0.658 K ₂ O)	0.6	0.6 max	0.6 max
Insoluble Residue	0.23	0.75 max	0.75 max
Compound Composition %			
Dicalcium Silicate (C ₂ S)	21.31	----	----
Tricalcium Silicate (C ₃ S)	54.34	----	----
Tricalcium Aluminate (C ₃ A)	5.01	----	8.0 max
Sum of Tricalcium Silicate and Tricalcium Aluminate	59.35	----	58.0 max
Tetracalcium Aluminoferrite (C ₄ AF)	10.6	----	----
Physical Properties			
Blaine fineness, m ² /kg	3772	160 min	160 min
No 325 fineness	92.7	----	----
Autoclave expansion, %	0.053	0.8 max	0.8 max
Setting time, Gilmore needlless (min.):			
Initial	133	60 min	60 min
Final	259	600 max	600 max
Setting time, Vicat (min.):			
Initial	61	45 min	45 min
Final	169	375 max	375 max
Air content of mortar, volume %	7.2	12 max	12 max
Compressive strength (psi) at:			
1 Day	1702	----	----
3 Days	2969	1740 min	1740 min
7 Days	3886	2760 min	2760 min
28 Days	5517	4060 min	4060 min

Table 3-2: Chemical and Physical Analysis of Fly Ash*

Chemical Composition, %	Class F	ASTM C 618-97 Specifications	
		Class F	Class C
Total Silica, Aluminum, Iron	81	70 min	50min
Silicon Dioxide	57.1	-----	-----
Aluminum Oxide	18.7	-----	-----
Iron Oxide	5.2	-----	-----
Sulfur Trioxide	0.7	5.0 max	5.0 max
Calcium Oxide	8.3	-----	-----
Moisture Content	0.4	3.0 max	3.0 max
Loss on Ignition	0.4	6.0 max	6.0 max
Physical Test Results			
Fineness, Retained on # 325 Sieve (%)	26.5	34 max	34 max
Strength Activity with Portland Cement:			
7 Day, % of Control	80.3	-----	-----
28 Day, % of Control	94.2	75 min	75 min
Water Requirement, % of Control	92.1	105 max	105 max
Soundness, Autoclave Expansion (%)	0.01	0.8 max	0.8 max
Density	2.38	-----	-----

* Chemical composition and physical data were provided by ISG Resources, INC.
Western Region

Table 3-3: Chemical Composition and Physical Properties of Silica Fume*

Chemical Composition	Percentage by Dry Mass
Silicon Dioxide (SiO ₂)	93.08
CL	0.19
Aluminum Oxide (Al ₂ O ₃)	1.17
Ferric Oxide (Fe ₂ O ₃)	0.19
Calcium Oxide (CaO)	0.43
Magnesium Oxide (MgO)	0.53
Sulfur Trioxide (SO ₃)	0.22
Sodium Oxide (Na ₂ O)	0.42
Potassium Oxide (K ₂ O)	1.18
Available Alkalies	1.27
Carbon (C)	3.47
Loss on Ignition	4.47
Physical Properties	
325 Sieve Retained (%)	3.44
Specific Gravity	2.2
Density - Fluffy (pcf)	10.5
Moisture Content (%)	0.14

* Chemical compositions and physical data were provided by Norchem Concrete Products Inc. in Fort Pierce, Florida

Table 3-4: Chemical and Physical Analysis of Metakaolin*

Chemical Analysis	Class N	ASTM C 618 Limits Class N	ASTM Test Method
Silicon Dioxide (SiO ₂)	53.4%	-----	-----
Aluminum Oxide (Al ₂ O ₃)	41.1%	-----	-----
Iron Oxide (Fe ₂ O ₃)	1.06%	-----	-----
Sum of Constituents	95.58%	70% min	D4326
Sulfur Trioxide (SO ₃)	0.09%	4.0% max	D4326
Calcium Oxide (CaO)	0.09%		D4326
Moisture Content	0.49%	3.0% max	C311
Loss on Ignition, % carbon	0.048%	10.0% max	C311
Available Alkalies, as Na ₂ O	0.0111%	1.5% max	C311
Physical Analysis			
Fineness, % Retained on # 325 Sieve	6.90%	-----	C311, C430
Strength Activity with Portland Cement:			
7 Day, % of Control	106%	75% min	C311, C109
28 Day, % of Control	124%	75% min	
Water Requirement, % Control	115%	115% max	-----
Autoclave Soundness	-0.05%	0.8% max	C311, C151
True Particle Density	2.29	-----	-----

* Chemical composition and physical data were provided by ISG Resources, INC.
Western Region

Table 3-5: Cement Paste Mix Compositions

Grout No.	w/cm	Mix Component											
		Water Content (gram)	Portland Cement II (gram)	HRWR (Grace) ADVA-100 (gram)	SRA (Grace) Eclipse (gram)	LRWR (Grace) WRAD-64 (gram)	HRWR (MB) Rheobuild-3000FC (gram)	SRA (MB) Tetraguard AS20 (gram)	Retarder (MB) Delvo (gram)	Fly Ash Class F (gram)	Silica Fume (gram)	Metakaolin Class N (gram)	Total Weight (gram)
1	0.33	330	1000	0									1330
2	0.33	328	1000	2									1330
3	0.33	326	1000	4									1330
4	0.33	324	1000	6									1330
5	0.33	322	1000	8									1330
6	0.33	325	1000		5								1330
7	0.33	315	1000		15								1330
8	0.33	305	1000		25								1330
9	0.33	321	1000	4	5								1330
10	0.33	311	1000	4	15								1330
11	0.33	301	1000	4	25								1330
12	0.33	330	1000			0							1330
13	0.33	329	1000			1							1330
14	0.33	328	1000			2							1330
15	0.33	327	1000			3							1330
16	0.33	326	1000	4		0							1330
17	0.33	325	1000	4		1							1330
18	0.33	324	1000	4		2							1330
19	0.33	323	1000	4		3							1330
20	0.33	319	1000	4	5	2							1330
21	0.33	314	1000	4	10	2							1330
22	0.33	309	1000	4	15	2							1330
23	0.33	304	1000	4	20	2							1330
24	0.33	299	1000	4	25	2							1330
25	0.33	328	950	2									1330
26	0.33	328	750	2							0	50	1330
27	0.33	328	700	2							200	50	1330
											250	50	1330

Table 3-5: Cement Paste Mix Compositions (Continued)

Grout No.	w/cm	Mix Component											Total Weight (gram)
		Water Content (gram)	Portland Cement II (gram)	HRWR (Grace) ADVA-100 (gram)	SRA (Grace) Eclipse (gram)	LRWR (Grace) WRAD-64 (gram)	HRWR Rheobuild-3000FC (gram)	SRA (MB) Tetraguard AS20 (gram)	Retarder (MB) Delvo (gram)	Fly Ash Class F (gram)	Silica Fume (gram)	Metakaolin Class N (gram)	
28	0.33	328	650	2						300		50	0
29	0.33	328	600	2						350		50	1330
30	0.33	328	950	2						0	50		1330
31	0.33	328	750	2						200	50		1330
32	0.33	328	700	2						250	50		1330
33	0.33	328	650	2						300	50		1330
34	0.33	328	600	2						350	50		1330
35	0.33	328	900	2								100	1330
36	0.33	328	800	2								200	1330
37	0.33	328	700	2								300	1330
38	0.33	328	900	2							100		1330
39	0.33	328	800	2							200		1330
40	0.33	328	700	2							300		1330
41	0.33	328	1000	2						0			1330
42	0.33	328	800	2						200			1330
43	0.33	328	750	2						250			1330
44	0.33	328	700	2						300			1330
45	0.33	328	650	2						350			1330
46	0.33	318	950	2	10					0		50	1330
47	0.33	318	750	2	10					200		50	1330
48	0.33	318	700	2	10					250		50	1330
49	0.33	318	650	2	10					300		50	1330
50	0.33	318	600	2	10					350		50	1330
51	0.33	303	950	2	25					0	50		1330
52	0.33	303	750	2	25					200	50		1330
53	0.33	303	700	2	25					250	50		1330
54	0.33	303	650	2	25					300	50		1330

Table 3-5: Cement Paste Mix Compositions (Continued)

Grout No.	w/cm	Mix Component											Total Weight (gram)
		Water Content (gram)	Portland Cement II (gram)	HRWR (Grace) ADVA-100 (gram)	SRA (Grace) Eclipse (gram)	LRWR (Grace) WRAD-64 (gram)	HRWR Rheobuild-3000FC (gram)	SRA (MB) Tetraguard AS20 (gram)	Retarder (MB) Delvo (gram)	Fly Ash Class F (gram)	Silica Fume (gram)	Metakaolin Class N (gram)	
55	0.33	303	600	2	25					350	50		0
56	0.33	330	1000				0						0
57	0.33	328	1000				2						1330
58	0.33	326	1000				4						1330
59	0.33	324	1000				6						1330
60	0.33	320	1000				10						1330
61	0.33	325	1000					5					1330
62	0.33	315	1000					15					1330
63	0.33	305	1000					25					1330
64	0.33	319	1000				6	5					1330
65	0.33	309	1000				6	15					1330
66	0.33	299	1000				6	25					1330
67	0.4	400	750							200		50	1400
68	0.45	450	750							200		50	1450
69	0.5	500	750							200		50	1500
70	0.55	550	750							200		50	1550
71	0.6	600	750							200		50	1600
72	0.4	400	750							200	50		1400
73	0.45	450	750							200	50		1450
74	0.5	500	750							200	50		1500
75	0.55	550	750							200	50		1550
76	0.6	600	750							200	50		1600
77	0.33	330	1000						0				1330
78	0.33	329	1000						1				1330
79	0.33	328	1000						2				1330
80	0.65	650	1000		0								1650
81	0.65	635	1000		15								1650

Table 3-6: Cement Paste Mix Proportions

Grout No.	w/cm	Mix Component										
		Water Content	Portland Cement II	HRWR (Grace) ADVA-100	SRA (Grace) Eclipse	LRWR (Grace) WRAD-64	HRWR (MB) Rheobuild 3000FC	SRA (MB) Tetraguard AS20	Retarder (MB) Delvo	Fly Ash Class F	Silica Fume	Metakaolin Class N
1	0.33	33	100	0								
2	0.33	32.8	100	0.2								
3	0.33	32.6	100	0.4								
4	0.33	32.4	100	0.6								
5	0.33	32.2	100	0.8								
6	0.33	32.5	100		0.5							
7	0.33	31.5	100		1.5							
8	0.33	30.5	100		2.5							
9	0.33	32.1	100	0.4	0.5							
10	0.33	31.1	100	0.4	1.5							
11	0.33	30.1	100	0.4	2.5							
12	0.33	33	100			0						
13	0.33	32.9	100			0.1						
14	0.33	32.8	100			0.2						
15	0.33	32.7	100			0.3						
16	0.33	32.6	100	0.4		0						
17	0.33	32.5	100	0.4		0.1						
18	0.33	32.4	100	0.4		0.2						
19	0.33	32.3	100	0.4		0.3						
20	0.33	31.9	100	0.4	0.5	0.2						
21	0.33	31.4	100	0.4	1	0.2						
22	0.33	30.9	100	0.4	1.5	0.2						
23	0.33	30.4	100	0.4	2	0.2						
24	0.33	29.9	100	0.4	2.5	0.2						
25	0.33	32.8	100	0.2						0		5
26	0.33	32.8	95	0.2						20		5
27	0.33	32.8	75	0.2						25		5

Table 3-6: Cement Paste Mix Proportions (Continued)

Grout No.	w/cm	Mix Component										
		Water Content	Portland Cement II	HRWR (Grace) ADVA-100	SRA (Grace) Eclipse	LRWR (Grace) WRAD-64	HRWR (MB) Rheobuild 3000FC	SRA (MB) Tetraguard AS20	Retarder (MB) Delvo	Fly Ash Class F	Silica Fume	Metakaolin Class N
28	0.33	32.8	70	0.2						30		5
29	0.33	32.8	65	0.2						35		5
30	0.33	32.8	60	0.2						0	5	
31	0.33	32.8	95	0.2						20	5	
32	0.33	32.8	75	0.2						25	5	
33	0.33	32.8	70	0.2						30	5	
34	0.33	32.8	65	0.2						35	5	
35	0.33	32.8	60	0.2								10
36	0.33	32.8	90	0.2								20
37	0.33	32.8	80	0.2								30
38	0.33	32.8	70	0.2							10	
39	0.33	32.8	90	0.2							20	
40	0.33	32.8	80	0.2							30	
41	0.33	32.8	70	0.2						0		
42	0.33	32.8	100	0.2						20		
43	0.33	32.8	80	0.2						25		
44	0.33	32.8	75	0.2						30		
45	0.33	32.8	70	0.2						35		
46	0.33	31.8	65	0.2	1					0		5
47	0.33	31.8	95	0.2	1					20		5
48	0.33	31.8	75	0.2	1					25		5
49	0.33	31.8	70	0.2	1					30		5
50	0.33	31.8	65	0.2	1					35		5
51	0.33	30.3	60	0.2	2.5					0	5	
52	0.33	30.3	95	0.2	2.5					20	5	
53	0.33	30.3	75	0.2	2.5					25	5	
54	0.33	30.3	70	0.2	2.5					30	5	
55	0.33	30.3	65	0.2	2.5					35	5	

Table 3-6: Cement Paste Mix Proportions (Continued)

Grout No.	w/cm	Mix Component										
		Water Content	Portland Cement II	HRWR (Grace) ADVA-100	SRA (Grace) Eclipse	LRWR (Grace) WRAD-64	HRWR (MB) Rheobuild 3000FC	SRA (MB) Tetraguard AS20	Retarder (MB) Delvo	Fly Ash Class F	Silica Fume	Metakaolin Class N
56	0.33	33	60				0					
57	0.33	32.8	100				0.2					
58	0.33	32.6	100				0.4					
59	0.33	32.4	100				0.6					
60	0.33	32	100				1					
61	0.33	32.5	100					0.5				
62	0.33	31.5	100					1.5				
63	0.33	30.5	100					2.5				
64	0.33	31.9	100				0.6	0.5				
65	0.33	30.9	100				0.6	1.5				
66	0.33	29.9	100				0.6	2.5				
67	0.4	40	75						20			5
68	0.45	45	75						20			5
69	0.5	50	75						20			5
70	0.55	55	75						20			5
71	0.6	60	75						20			5
72	0.4	40	75						20	5		
73	0.45	45	75						20	5		
74	0.5	50	75						20	5		
75	0.55	55	75						20	5		
76	0.6	60	75						20	5		
77	0.33	33	100						0			
78	0.33	32.9	100						0.1			
79	0.33	32.8	100						0.2			
80	0.65	65	100		0							
81	0.65	63.5	100		1.5							

Figure 3-1: Shrinkage versus Age for Cement Paste Containing Different Dosages of HRWR-G

Figure 3-2: Shrinkage versus Age for Cement Paste Containing Different Dosages of SRA-G

Figure 3-3: Shrinkage versus Age for Cement Paste Containing Different Dosages of SRA-G (0.4% HRWR-G)

Figure 3-4: Shrinkage versus Age for Cement Paste
Containing Different Dosages of LRWR-G

Figure 3-5: Shrinkage versus Age for Cement Paste
Containing Different Dosages of LRWR-G
(0.4 % HRWR-G)

Figure 3-6: Shrinkage versus Age for Cement Paste
Containing Different Dosages of SRA-G
(0.4% HRWR-G, 0.2% LRWR-G)

Figure 3-7: Shrinkage versus Age for Cement Paste
Containing Different Dosages of Metakaolin
(0.2% HRWR-G)

Figure 3-8: Shrinkage versus Age for Cement Paste
Containing Different Dosages of Silica Fume
(0.2% HRWR-G)

Figure 3-9: Shrinkage versus Age for Cement Paste
Containing Different Dosages of Fly Ash
(0.2% HRWR-G)

Figure 3-10: Shrinkage versus Age for Cement Paste
Containing Different Dosages of Fly Ash
(5% Metak, 0.2% HRWR-G)

Figure 3-11: Shrinkage versus Age for Cement Paste
Containing Different Dosages of Fly Ash
(5% SF, 0.2% HRWR-G)

Figure 3-12: Shrinkage versus Age for Cement Paste
Containing Different Dosages of Fly Ash
(5% Metak, 0.2% HRWR-G, 1% SRA-G)

Figure 3-13: Shrinkage versus Age for Cement Paste
Containing Different Dosages of Fly Ash
(5% SF, 0.2% HRWR-G, 2.5% SRA-G)

Figure 3-14: Shrinkage versus Age for Cement Paste
Containing Different Dosages of HRWR-MB

Figure 3-15: Shrinkage versus Age for Cement Paste
Containing Different Dosages of SRA-MB

Figure 3-16: Shrinkage versus Age for Cement Paste
Containing Different Dosages of SRA-MB
(0.6% HRWR-MB)

Figure 3-17: Shrinkage versus Age for Cement Paste
Containing Different w/cm Ratio
(5% Metak, 20% FA)

Figure 3-18: Shrinkage versus Age for Cement Paste
Containing Different w/cm Ratio
(5% SF, 20% FA)

Figure 3-19 : Shrinkage versus Age for Cement Paste
Containing Different Dosages of Delvo Stabilizer

Figure 3-20: Shrinkage versus Age for Cement Paste
Containing Different Dosages of SRA-G
(0.33% w/cm or 0.65% w/cm)

Chapter 4

Effect of Admixtures on High Strength Concrete

4.1 Introduction

This chapter describes the effects of various types of admixtures on the drying shrinkage and compressive strength of concrete. The concretes included in this study contain cement, water, coarse and fine aggregate, and mineral and chemical admixtures. Three types of mineral admixtures were used. These are fly ash class F, silica fume, and metakaolin (calcine clay, class N). Also three types of chemical admixtures produced by either Master Builder or W.R. Grace were utilized. These are shrinkage reducing admixture, high-range water reducing admixture, and low-range water reducing admixture. Tests were conducted to evaluate shrinkage, expansion, and compressive strength of the concrete with different admixtures according to ASTM C 157.

4.2 Properties of Concrete Constituents

4.2.1 Cement

ASTM type II Portland cement was used in this study. The cement meets ASTM C 150 specifications. Chemical compositions and physical properties of the cement are given in Table 3-1.

4.2.2 Admixtures

The admixtures used in this study were divided in two categories:

1) Mineral Admixtures

A. Fly Ash class F- normally produced from burning anthracite bituminous coal and this class fly ash has pozzolanic properties. The chemical and physical compositions of the fly ash are given in Table 3-2 in accordance to ASTM C 618.

B. Silica Fume- very fine non-crystalline silica (SiO_2) produced by electric arc furnaces as a by-product of the production of metallic silicon or ferrosilicon alloys. The chemical composition and physical properties of the silica fume are given in Table 3-3.

C. Metakaolin (calcine clay, class N)- is calcined kaolin clay with approximately 1.5% loss on ignition, and contains less than 1% quartz. The chemical and physical compositions of the metakaolin are given in Table 3-4.

2) Chemical admixtures

W.R. Grace Products:

A. SRA-G (Eclipse) is a shrinkage-reducing admixture no ASTM specifications available at this time.

- B. HRWR-G (ADVA-100, superplasticizer) is high-range water-reducing admixture. It is an admixture that reduces the quantity of mixing water required.
- C. LRWR-G (WRAD-64) is a low-range water-reducing admixture. It is an admixture that reduces the quantity of mixing water required to produce concrete of a given consistency. It meets ASTM C 494-90 specifications.

Master Builder Products:

- D. SRA-MB (Tetraguard-AS20) is a shrinkage-reducing admixture. It is an admixture that reduces the drying shrinkage. No ASTM specifications available at this time.
- E. HRWR-MB (Rheobuild-3000 FC) is high-range water-reducing admixture, ASTM No. ASTM C 494 Type A and F.
- F. LRWR-MB (Pozzolith 200N) is a low-range water-reducing admixture. It is an admixture that reduces the quantity of mixing water required to produce concrete of a given consistency.

4.2.3 Aggregate

The coarse aggregate used in this study was limestone and crushed granite. The maximum size of the aggregate was ½-in. The aggregate was produced at the

Sechelt, B.C. plant, and was distributed at Hanson's Bay area facilities. The sieve analysis of aggregates was performed in accordance to ASTM C 33.

The Results of sieve analyses for $\frac{1}{2}$ -in. aggregate are summarized in Table 4-1, and Figure 4-1.

The fine aggregate had a fineness modulus of 2.77. The result of sieve analysis is summarized in Table 4-1, and Figure 4-2.

Physical properties of coarse and fine aggregates are summarized in Table 4-2.

4.3 Mix Design

A total of thirty-four concrete mixes were made in this study to investigate the effect of different types of admixtures. The concrete mixes were made with type II Portland cement and have w/cm of 0.33 by weight of cementitious material except last three mixes with 0.34 w/cm ratio. Table 4-3 and 4-4 describe the mix compositions and proportions.

4.4 Mixing Procedure

The following mixing procedure was used in this study:

1. Wet the drum mixer and drain the water.
2. Add coarse aggregate followed with $\frac{1}{4}$ water.
3. Add silica fume to bond coarse aggregate.
4. Add fine aggregate with another $\frac{1}{4}$ water.
5. Add cement and fly ash at the same time.

6. Keep adding water after each solid.
7. Add superplasticizer by itself or mix by water at the end.
8. Mix for two – five minutes after all components are added, let stand for two minutes, then mix for additional three minutes.

Three concrete prisms with dimensions 3 x 3 x 11 ¼-in. (75 x 75 x 285-mm) and twelve 4 x 8-in. (100 x 200-mm) cylinders were prepared for each mix.

The concrete prisms were left to cure for 24 hours in a moist room (100% humidity) while they were covered with a plastic sheet. The specimens were then demolded and initial reading was taken by using comparator in accordance to ASTM C 490. The specimens were placed in a bathtub in a moist room for six days, and second reading was taken.

The specimens were then placed in a controlled room temperature at $73.4^{\circ} \pm 3^{\circ}\text{F}$ ($23^{\circ} \pm 1.7^{\circ}\text{C}$) with a relative humidity of $50\% \pm 4\%$. Shrinkage readings were taken at different time intervals up to 180 days. Shrinkage was determined in accordance to ASTM C 157.

The 4 x 8-in. (100 x 200-mm) and 6 x 12-in. (150 x 300-mm) concrete cylinders were left to cure in a moist room for hundred and eighty days. The specimens were tested for compressive strength at 28, 56, 90, and 180 days. Also the modulus of elasticity was determined at 28, 56, 90, and 180 days.

4.5 Test Results and Discussion

4.5.1 Shrinkage

Shrinkage data versus age are plotted and tabulated up to 180 days in Appendix III and Appendix IV. Shrinkage Data versus age up to 180 days for concrete mixes with 0.33 w/cm ratio with initial reading taken after seven days are plotted in Appendix III (one day in mold and six days in water). Shrinkage data and expansion versus age up to 180 days for concrete mixes with 0.33 w/cm ratio with the initial reading taken after one day are plotted in Appendix IV.

The data and graphs described in this chapter are from the results of Appendix III. The effect of different admixtures on the shrinkage of concrete is showed in Figures 4-3 through 4-18.

Figure 4-3 shows the effect of fly ash replaced by total weight of cement at different percentage 20%, 25%, and 30% with 5% silica fume, 0.6% HRWR-G, and 0.33 w/cm ratio. It can be observed that increasing the dosage of fly ash from 20% to 30% has no significant effect on drying shrinkage.

Figure 4-4 shows the effect of fly ash replaced by total weight of cement at different percentage 20%, 25%, and 30% with 5% metakaolin, 0.6% HRWR-G, and 0.33 w/cm ratio. It can be observed that increasing dosage of fly ash from 20% to 30% has no significant effect on drying shrinkage.

Figure 4-5 shows the effect of fly ash replaced by total weight of cement at different percentage 20%, 25%, and 30% with 5% silica fume, 0.6% HRWR-G

0.5% SRA-G, and 0.33 w/cm ratio. It can be observed that increasing fly ash from 20% to 30% does not affect drying shrinkage. When comparing Figure 4-5 to Figure 4-3 it can be observed that addition a dosage of 0.5% SRA-G reduces the drying shrinkage by 36% at 180 days.

Figure 4-6 shows the effect of fly ash replaced by total weight of cement at different percentage 20%, 25%, and 30% with 5% metakaolin, 0.6% HRWR-G, 0.5% SRA-G, and 0.33 w/cm ratio. It can be observed that increasing fly ash from 20% to 30% does not affect drying shrinkage. When comparing Figure 4-6 to 4-4 it can be observed that the addition a dosage of 0.5% SRA-G reduces the drying shrinkage by 10% at 180 days.

The effects of metakaolin and silica fume for concrete with and without SRA-G are plotted in Figures 4-7 through 4-12.

Figures 4-7 shows the effect of different dosages of SRA-G with 20% fly ash, 5% silica fume, 0.6% HRWR-G, and 0.33 w/cm ratio. It can be observed that the addition of SRA-G at dosage of 0.5% reduces the drying shrinkage by 30% at 180 days.

Figure 4-8 shows the effect of different dosages of SRA-G with 25% fly ash, 5% silica fume, 0.6% HRWR-G, and 0.33 w/cm ratio. The graph indicates that addition of SRA-G at dosage of 0.5% reduces the drying shrinkage by 29% at 180 days.

Figure 4-9 shows the effect of different dosages of SRA-G with 30% fly ash, 5% silica fume, 0.6% HRWR-G, and 0.33 w/cm ratio. The graph indicates that addition of SRA-G at dosage of 0.5% reduces the drying shrinkage by 36% at 180 days.

Figure 4-10 shows the effect of different dosages of SRA-G with 20% fly ash, 5% metakaolin, 0.6% HRWR-G, and 0.33 w/cm ratio. It can be observed that addition of SRA-G at dosage of 0.5% reduces the drying shrinkage by 19% at 180 days.

Figure 4-11 shows the effect of different dosages of SRA-G with 25% fly ash, 5% metakaolin, 0.6% HRWR-G, and 0.33 w/cm ratio. The graph shows the addition of SRA-G at dosage of 0.5% reduces the drying shrinkage by 20% at 180 days.

Figure 4-12 shows the effect of different dosages of SRA-G with 30% fly ash, 5% metakaolin, 0.6% HRWR-G, and 0.33 w/cm ratio. The graph indicates that addition of SRA-G at dosage of 0.5% has no significant effect on the drying shrinkage.

Figure 4-13 shows the effect of different dosages of SRA-MB with 25% fly ash, 5% silica fume, 0.6% HRWR-MB, and 0.33 w/cm ratio. It can be observed that dosage of SRA-MB at 0.5% reduces the drying shrinkage by 43% at 180 days.

Figure 4-14 shows the effect of different dosages of HRWR-MB and LRWR-MB. It can be observed that 0.6% HRWR-MB has the same effect on drying shrinkage as 0.4% HRWR-MB and 0.2% LRWR-MB. (no effect on drying shrinkage)

Figure 4-15 shows the effect of different dosages of SRA-G with 25% fly ash, 5% silica fume, 0.6% HRWR-G and 0.33 w/cm ratio. It can be observed that dosage of

SRA-G at 2.5% reduces the drying shrinkage by 57% at 180 days. In addition, dosage of SRA-G from 1.5% to 2.5% does not have significant effect on drying shrinkage.

Figure 4-16 shows the effect of different dosages of SRA-G with 25% fly ash, 5% silica fume, 0.4% HRWR-G, 0.2% LRWR-G, and 0.33 w/cm ratio. The figure indicates that dosage of SRA-G at 2.5% reduces the drying shrinkage by 56% at 180 days. In addition, a dosage of SRA-G from 1.5% to 2.5% does not have significant effect on drying shrinkage.

Figure 4-17 shows the effect of different dosages of SRA-MB with 25% fly ash, 5% silica fume, 0.4% HRWR-MB, 0.2% LRWR-MB, and 0.33 w/cm ratio. It can be observed from the figure that dosage of SRA-MB at 2.5% reduces the drying shrinkage by 45% at 180 days. Furthermore, SRA-MB from 1.5% to 2.5% has no significant effect on drying shrinkage. And also, it can be observed that the effect of different dosages of SRA-MB with 0.4% HRWR-MB and 0.2% LRWR-MB is the same as the effect of different dosages of SRA-G with 0.4% HRWR-G and 0.2% LRWR-G.

Figure 4-18 shows the effect of different cement content (sack) with different aggregate-to-cementitious (A/cm) materials ratio. It can be observed that increasing A/cm ratio from 4.76 to 4.80 with the same cement content reduces the drying shrinkage by 12% at 180 days.

4.5.2 Compressive Strength

The compressive strength versus age for concrete mixes containing different mineral and chemical admixtures is shown in Figures 4-19 through 4-29. The compressive

strength data were obtained at different ages of 28, 56, 90 and 180 days. The compressive strength data were obtained from testing 4 x 8-in. (100 x 200-mm) cylinders for all mixes. In addition, 6 x 12-in. (150 x 300-mm) concrete cylinders were made for mix 31 through 34 for comparison.

Figure 4-19 shows the compressive strength versus age for different dosages of fly ash and SRA-G with 5% silica fume, 0.6% HRWR-G. It can be observed that increasing the dosage of fly ash from 20% to 30% and dosage of SRA-G from 0% to 0.5% decrease the compressive strength by 9%.

Figure 4-20 shows the compressive strength versus age of different dosages of fly ash and SRA-G with 5% metakaolin, 0.6% HRWR-G. It can be observed that increasing dosage of fly ash from 20% to 30% and dosage of SRA-G from 0% to 0.5% decrease the compressive strength by 5%.

Figure 4-21 shows the compressive strength versus age of different dosages of SRA-G with 20% fly ash, 5% silica fume, 5% metakaolin, and 0.6% HRWR-G. It can be observed that addition dosage of SRA-G from 0% to 0.5% with 5% silica fume decrease the compressive strength by 5% higher than 5% metakaolin.

Figure 4-22 shows the compressive strength versus age of different dosages of SRA-G with 25% fly ash, 5% silica fume, 5% metakaolin, and 0.6% HRWR-G. It can be observed that addition dosage of SRA-G from 0% to 0.5% SRA-G with 5% silica fume decrease the compressive strength by 19% higher than 5% metakaolin.

Figure 4-23 shows the compressive strength versus age of different dosages of

SRA-G with 30% fly ash, 5% silica fume, 5% metakaolin, and 0.6% HRWR-G. It can be observed that addition dosage of SRA-G from 0% to 0.5% with 5% silica fume decrease the compressive strength by 14% higher than 5% metakaolin.

Figure 4-24 shows the compressive strength versus age of different dosages of HRWR-MB and LRWR-MB with 25% fly ash, and 5% silica fume. It can be observed that decreasing dosage of HRWR-MB from 0.6% to 0.4% reduces the compressive strength by 13%.

Figure 4-25 shows the compressive strength versus age of different dosages of SRA-G with 25% fly ash, 5% silica fume, and 0.6% HRWR-G. It can be observed that addition different dosage of SRA-G from 0% to 2.5% reduces the compressive strength by 10%.

Figure 4-26 shows the compressive strength versus age of different dosages of SRA-G with 0.4% HRWR-G, 0.2% LRWR-G, 25% fly ash and 5% silica fume. It can be observed that increasing dosage of SRA-G from 0% to 2.5% reduces the compressive strength by 4%. Furthermore, comparison of Figure 4-25 with 4-26 shows that decreasing dosage of HRWR-G from 0.6% to 0.4% decreases the compressive strength by 5%.

Figure 4-27 shows the compressive strength versus age of different dosages of SRA-MB with 0.4% HRWR-MB, 0.2% LRWR-MB, 25% fly ash and 5% silica fume. It can be observed that increasing dosages of SRA-MB from 0% to 2.5% reduce the compressive strength by 3%.

Figure 4-28 shows the compressive strength versus age of different dosage of cement content (sack) and A/cm ratio (4 x 8-in. cylinders). It can be observed that increasing A/cm ratio from 4.76 to 4.80 with the same cement content increases the compressive strength by 15%.

Figure 4-29 shows the compressive strength versus age of different dosage of cement content (sack) and A/cm ratios (6 x 12-in. cylinders). It can be observed that increasing A/cm ratio from 4.76 to 4.80 with the same cement content increases the compressive strength by 9%. This shows that the compressive strength of 6 x 12-in. cylinder is lower than the compressive strength of 4 x 8-in. cylinder.

4.6 Summary

The purpose of this study was to investigate the effect of chemical and mineral admixtures on drying shrinkage and compressive strength of concrete mixes.

4.6.1 Drying shrinkage of HSC

The effect of chemical and mineral admixtures on drying shrinkage of HSC is summarized as follows:

1. Fly ash replaced by total weight of cement at different percentage 20%, 25% and 30% with 5% silica fume and 0.6% HRWR-G has no significant effect on drying shrinkage.
2. Fly ash replaced by total weight of cement at different percentage 20%, 25% and 30% with 5% metakaolin and 0.6% HRWR-G has no significant effect on drying shrinkage.
3. Fly ash replaced by total weight of cement at different percentage 20%, 25% and 30% with 5% silica fume, 0.6% HRWR-G, and 0.5% SRA-G does not affect drying shrinkage. Furthermore, addition dosage of 0.5% SRA-G reduces the drying shrinkage by 36% at 180 days.
4. Fly ash replaced by total weight of cement at different percentage 20%, 25% and 30% with 5% metakaolin, 0.6% HRWR-G, and 0.5% SRA-G does not affect drying shrinkage. Furthermore, addition dosage of 0.5% SRA-G reduces the drying shrinkage by 10% at 180 days.

5. Different dosages of SRA-G from 0% to 0.5% with 20% fly ash, 5% silica fume, and 0.6% HRWR-G reduce drying shrinkage by 30% at 180 days.
6. Different dosages of SRA-G from 0% to 0.5% with 25% fly ash, 5% silica fume, and 0.6% HRWR-G reduce drying shrinkage by 29% at 180 days.
7. Different dosages of SRA-G from 0% to 0.5% with 30% fly ash, 5% silica fume, and 0.6% HRWR-G reduce drying shrinkage by 36% at 180 days.
8. Different dosages of SRA-G from 0% to 0.5% with 20% fly ash, 5% metakaolin, and 0.6% HRWR-G reduce drying shrinkage by 19% at 180 days.
9. Different dosages of SRA-G from 0% to 0.5% with 25% fly ash, 5% metakaolin, and 0.6% HRWR-G reduce drying shrinkage by 20% at 180 days.
10. Different dosages of SRA-G from 0% to 0.5% with 30% fly ash, 5% metakaolin, and 0.6% HRWR-G do not affect the drying shrinkage.
11. 0.6% HRWR-MB has the same effect as 0.4% HRWR-MB with 0.2% LRWR-MB on the drying shrinkage (i.e. no effect on drying shrinkage).
12. Different dosage of SRA-MB from 0% to 0.5 % reduces the drying shrinkage by 34% at 180 days.
13. Different dosages of SRA-G of 0%, 0.5%, 1%, 1.5%, 2% and 2.5% with 25% fly ash, 5% silica fume, and 0.6% HRWR-G reduces the drying shrinkage by 57% at 180 days. Furthermore, SRA-G above 1.5% to 2.5% has no additional effect on drying shrinkage.
14. Different dosages of SRA-G of 0%, 0.5%, 1%, 1.5%, 2% and 2.5% with 25% fly ash, 5% silica fume, 0.4% HRWR-G, and 0.2% LRWR-G reduces the drying shrinkage by

56% at 180 days. Furthermore, SRA-G above 1.5% to 2.5% has no additional effect on drying shrinkage.

15. Different dosages of SRA-MB of 0%, 1%, 1.5%, 2% and 2.5% with 25% fly ash, 5% silica fume, 0.4% HRWR-MB, and 0.2% LRWR-MB reduces the drying shrinkage by 45% at 180 days. Furthermore, SRA-MB above 1.5% to 2.5% has no significant effect on drying shrinkage.
16. The effect of different dosages of SRA-G with 0.4% HRWR-G and 0.2% LRWR-G is the same as the effect of different dosages of SRA-MB with 0.4% HRWR-MB and 0.2% LRWR-MB on the drying shrinkage.
17. Increasing A/cm ratio from 4.76 to 4.80 decreases the drying shrinkage by 10% at 180 days. Furthermore, dosage of A/cm from 4.80 to 5.28 has no significant effect on drying shrinkage.

4.6.2 Compressive strength of HSC

The effect of chemical and mineral admixtures on compressive strength of HSC is summarized as follows:

18. Fly ash replaced by total weight of cement at different percentage 20%, 25% and 30% and SRA-G from 0% to 0.5% with 5% silica fume decrease the compressive strength by 9%.
19. Fly ash replaced by total weight of cement at different percentage 20%, 25% and 30% and SRA-G from 0% to 0.5% with 5% metakaolin decrease the compressive strength by 5%.

20. Different dosages of SRA-G from 0% to 0.5% with 20% fly ash, and 5% silica fume reduce the compressive strength by 5% higher than 5% metakaolin.
21. Different dosages of SRA-G from 0% to 0.5% with 25% fly ash, and 5% silica fume reduce the compressive strength by 19% higher than 5% metakaolin.
22. Different dosages of SRA-G from 0% to 0.5% with 30% fly ash, and 5% silica fume reduce the compressive strength by 14% higher than 5% metakaolin.
23. Different dosages of HRWR-MB and LRWR-MB reduce the compressive strength by 13%.
24. Different dosages of SRA-G 0%, 0.5%, 1%, 1.5%, 2% and 2.5% with 25% fly ash, 5% silica fume, 0.6% HRWR-G, reduce the compressive strength by 10%.
25. Different dosages of SRA-G 0%, 0.5%, 1%, 1.5%, 2% and 2.5% with 25% fly ash, 5% silica fume, 0.4% HRWR-G, and 0.2% LRWR-G reduce the compressive strength by 4%.
26. Different dosages of SRA-MB 0%, 1%, 1.5%, 2% and 2.5% with 25% fly ash, 5% silica fume, 0.4% HRWR-MB, and 0.2% LRWR-MB reduce the compressive strength by 5%.
27. Increasing A/cm ratio from 4.76 to 4.80 (4 x 8-in.) cylinders increases the compressive strength by 15%. Furthermore, the compressive strength of 6 x 12-in. cylinders is lower than 4 x 8-in. cylinders.

Table 4-1: Results of the Sieve Analysis (Hanson Aggregate)

1/2 in. Coarse Aggregate				Fine Aggregate			
ASTM C 33 Sieve Analysis	Percent Passing		ASTM C 33 Spec. Size 7	ASTM C 33 Sieve Analysis	Percent Passing		ASTM C 33 Spec.
	Sechelt 1/2"x #4	Caltrans 1/2"x #4			Sechelt Conc. Sand	Caltrans Spec. Sec. 90	
3/4"	100	100	100	3/8"	100	100	100
1/2"	95	82 - 100	90 - 100	No. 4	99	95 - 100	95 - 100
3/8"	63	40 - 78	40 - 70	No. 8	89	65 - 95	80 - 100
No. 4	2	0 - 15	0 - 15	No. 16	70	55 - 75	50 - 85
No. 8	1	0 - 6	0 - 5	No. 30	47	34 - 46	25 - 60
				No. 50	19	16 - 29	10 - 30
				No. 100	5	2 - 12	2 - 10
				No. 200	1	0 - 8	0 - 3

Table 4-2: Physical Properties of Aggregate (Hanson Aggregate)

Coarse Aggregate		Fine Aggregate	
Bulk Specific Gravity (SSD)	2.69	Bulk Specific Gravity (SSD)	2.65
Absorption, %	0.8	Fineness Modulus	2.77
		Absorption, %	0.9

Figure 4-1: Sieve Analysis for 1/2-in. Coarse Aggregate
(Sechelt B.C. Plant)

Figure 4-2: Sieve Analysis for Fine Aggregate
(Sechelt, B.C. Plant)

Table 4-3: Concrete Mix Compositions

Mix No.	Water (lb/cyd)	Cement (lb/cyd)	HRWR (Grace) ADVA-100 (oz/cyd)	SRA (Grace) Eclipse (oz/cyd)	LRWR (Grace) WRAD-64 (oz/cyd)	HRWR (MB) Rheobuild 3000FC (oz/cyd)	SRA (MB) Tetraguard (oz/cyd)	LRWR (MB) Pozzolith (oz/cyd)	Fly Ash Class F (lb/cyd)	Silica Fume (lb/cyd)	Meta-kaolin Class N (lb/cyd)	Coarse Agg. (1/2 in.) (lb/cyd)	Fine Agg. (lb/cyd)
1	208	473	57.6	50.4	---	---	---	---	126	32	---	1752	1564
2	208	473	57.6	---	---	---	---	---	126	32	---	1752	1564
3	208	473	57.6	---	---	---	---	---	126	---	32	1752	1564
4	208	473	57.6	50.4	---	---	---	---	126	---	32	1752	1564
5	208	441	57.6	---	---	---	---	---	158	32	---	1752	1564
6	208	441	57.6	---	---	---	---	---	158	---	32	1752	1564
7	208	441	57.6	50.4	---	---	---	---	158	32	---	1752	1564
8	208	441	57.6	50.4	---	---	---	---	158	---	32	1752	1564
9	208	410	57.6	---	---	---	---	---	189	32	---	1752	1564
10	208	410	57.6	---	---	---	---	---	189	---	32	1752	1564
11	208	410	57.6	50.4	---	---	---	---	189	---	32	1752	1564
12	208	410	57.6	50.4	---	---	---	---	189	32	---	1752	1564
13	208	441	57.6	100.8	---	---	---	---	158	32	---	1752	1564
14	208	441	57.6	151.3	---	---	---	---	158	32	---	1752	1564
15	208	441	57.6	201.7	---	---	---	---	158	32	---	1752	1564
16	208	441	57.6	252.1	---	---	---	---	158	32	---	1752	1564
17	208	441	38.4	---	19.2	---	---	---	158	32	---	1752	1564
18	208	441	38.4	50.4	19.2	---	---	---	158	32	---	1752	1564
19	208	441	38.4	100.8	19.2	---	---	---	158	32	---	1752	1564
20	208	441	38.4	151.3	19.2	---	---	---	158	32	---	1752	1564
21	208	441	38.4	201.7	19.2	---	---	---	158	32	---	1752	1564
22	208	441	38.4	252.1	19.2	---	---	---	158	32	---	1752	1564
23	208	441	---	---	---	57.6	---	---	158	32	---	1752	1564
24	208	441	---	---	---	57.6	50.4	---	158	32	---	1752	1564
25	208	441	---	---	---	38.4	---	19.2	158	32	---	1752	1564
26	208	441	---	---	---	38.4	50.4	19.2	158	32	---	1752	1564
27	208	441	---	---	---	38.4	100.8	19.2	158	32	---	1752	1564

Table 4-3: Concrete Mix Compositions (Continued)

Mix No.	Water (lb/cyd)	Cement (lb/cyd)	HRWR (Grace) ADVA-100 (oz/cyd)	SRA (Grace) Eclipse (oz/cyd)	LRWR (Grace) WRAD-64 (oz/cyd)	HRWR (MB) Rheobuild 3000FC (oz/cyd)	SRA (MB) Tetraguard (oz/cyd)	LRWR (MB) Pozzolith (oz/cyd)	Fly Ash Class F (lb/cyd)	Silica Fume (lb/cyd)	Meta-kaolin Class N (lb/cyd)	Coarse Agg. (1/2 in.) (lb/cyd)	Fine Agg. (lb/cyd)
28	208	441				38.4	151.3	19.2	158	32	---	1752	1564
29	208	441				38.4	201.7	19.2	158	32	---	1752	1564
30	208	441				38.4	252.1	19.2	158	32	---	1752	1564
31	223	474	41.2		20.6				169	---	32	1752	1485
32	230	474	41.2		20.6				169	---	32	1752	1460
33	213	439	38.2		19.1				157	---	32	1752	1564
34	240	494	43		21.5				176	---	32	1752	1413

Table 4-4: Concrete Mix Proportions

Mix No.	*w/cm	HRWR (Grace) ADVA-100	SRA (Grace) Eclipse	LRWR (Grace) WRAD-64	HRWR (MB) Rheobuild 3000FC	SRA (MB) Tetraguard AS20	LRWR (MB) Pozzolith 200N	Fly Ash Class F	Silica Fume Class N	Meta-kaolin Class N	**A/cm	***CA/FA	Fineness Fine Aggregate	CA vol. Per unit wt. Concr.
1	0.33	0.6	0.5					20	5		5.25	1.12	2.77	0.64
2	0.33	0.6	0.0					20	5		5.25	1.12	2.77	0.64
3	0.33	0.6	0.0					20		5	5.25	1.12	2.77	0.64
4	0.33	0.6	0.5					20		5	5.25	1.12	2.77	0.64
5	0.33	0.6	0.0					25	5		5.25	1.12	2.77	0.64
6	0.33	0.6	0.0					25		5	5.25	1.12	2.77	0.64
7	0.33	0.6	0.5					25	5		5.25	1.12	2.77	0.64
8	0.33	0.6	0.5					25		5	5.25	1.12	2.77	0.64
9	0.33	0.6	0.0					30	5		5.25	1.12	2.77	0.64
10	0.33	0.6	0.0					30		5	5.25	1.12	2.77	0.64
11	0.33	0.6	0.5					30		5	5.25	1.12	2.77	0.64
12	0.33	0.6	0.5					30	5		5.25	1.12	2.77	0.64
13	0.33	0.6	1.0					25	5		5.25	1.12	2.77	0.64
14	0.33	0.6	1.5					25	5		5.25	1.12	2.77	0.64
15	0.33	0.6	2.0					25	5		5.25	1.12	2.77	0.64
16	0.33	0.6	2.5					25	5		5.25	1.12	2.77	0.64
17	0.33	0.4	0.0	0.2				25	5		5.25	1.12	2.77	0.64
18	0.33	0.4	0.5	0.2				25	5		5.25	1.12	2.77	0.64
19	0.33	0.4	1.0	0.2				25	5		5.25	1.12	2.77	0.64
20	0.33	0.4	1.5	0.2				25	5		5.25	1.12	2.77	0.64
21	0.33	0.4	2.0	0.2				25	5		5.25	1.12	2.77	0.64
22	0.33	0.4	2.5	0.2				25	5		5.25	1.12	2.77	0.64
23	0.33				0.6	0		25	5		5.25	1.12	2.77	0.64
24	0.33				0.6	0.5		25	5		5.25	1.12	2.77	0.64
25	0.33				0.4	0	0.2	25	5		5.25	1.12	2.77	0.64
26	0.33				0.4	0.5	0.2	25	5		5.25	1.12	2.77	0.64
27	0.33				0.4	1	0.2	25	5		5.25	1.12	2.77	0.64

Table 4-4: Concrete Mix Proportions (Continued)

Mix No.	*w/cm	HRWR (Grace) ADVA-100	SRA (Grace) Eclipse WRAD-64	LRWR (Grace)	HRWR (MB) Rheobuild 3000FC	SRA (MB) Tetraguard AS20	LRWR (MB) Pozzolith 200N	Fly Ash Class F	Silica Fume	Meta-kaolin Class N	**A/cm	***CA/FA	Fineness Fine Aggregate	CA vol. Per unit wt. Concr.
28	0.33				0.4	1.5	0.2	25	5		5.25	1.12	2.77	0.64
29	0.33				0.4	2.0	0.2	25	5		5.25	1.12	2.77	0.64
30	0.33				0.4	2.5	0.2	25	5		5.25	1.12	2.77	0.64
31	0.33	0.4	0.0	0.2				25		5	4.80	1.18	2.77	0.64
32	0.34	0.4	0.0	0.2				25		5	4.76	1.20	2.77	0.64
33	0.34	0.4	0.0	0.2				25		5	5.28	1.12	2.77	0.64
34	0.34	0.4	0.0	0.2				25		5	4.51	1.24	2.77	0.64

* w/cm = Water-to-cementitious materials ratio by weight

** A/cm = Aggregate-to-cementitious materials ratio by weight

*** CA/FA = Coarse aggregate-to-fine aggregate ratio by weight

Mixes containing ASTM Type II cement.

Note: Mixes 1 through 30 Cement Content= 631 lb/cy (6.70 Sacks)
 Mixes 31 and 32 Cement Content= 675 lb/cy (7.18 Sacks)
 Mix 33 Cement Content= 628 lb/cy (6.68 Sacks)
 Mix 34 Cement Content= 702 lb/cy (7.47 Sacks)

Figure 4-3: Shrinkage versus Age for Concrete Containing Different Dosages of Fly Ash (5% SF, 0.6% HRWR-G)

Figure 4-4: Shrinkage versus Age for Concrete Containing Different Dosages of Fly Ash (5% Metak, 0.6% HRWR-G)

Figure 4-5: Shrinkage versus Age for Concrete Containing Different Dosages of Fly Ash (5% SF, 0.6% HRWR-G, 0.5% SRA-G)

Figure 4-6: Shrinkage versus Age for Concrete Containing Different Dosages of Fly Ash
(5% Metak, 0.6% HRWR-G, 0.5% SRA-G)

Figure 4-7: Shrinkage versus Age for Concrete Containing Different Dosages of SRA-G
(5% SF, 20% FA, 0.6% HRWR-G)

Figure 4-8: Shrinkage versus Age for Concrete Containing Different Dosages of SRA-G
(5% SF, 25% FA, 0.6% HRWR-G)

Figure 4-9: Shrinkage versus Age for Concrete Containing Different Dosages of SRA-G
(5% SF, 30% FA, 0.6% HRWR-G)

Figure 4-10: Shrinkage versus Age for Concrete Containing Different Dosages of SRA-G
(5% Metak, 20% FA, 0.6% HRWR-G)

Figure 4-11: Shrinkage versus Age for Concrete Containing Different Dosages of SRA-G
(5% Metak, 25% FA, 0.6% HRWR-G)

Figure 4-12: Shrinkage versus Age for Concrete Containing Different Dosages of SRA-G
(5% Metak, 30% FA, 0.6% HRWR-G)

Figure 4-13: Shrinkage versus Age for Concrete Containing Different Dosages of SRA-MB
(5% SF, 25% FA, 0.6% HRWR-MB)

Figure 4-14: Shrinkage versus Age for Concrete Containing Different Dosages of HRWR-MB and LRWR-MB
(25% FA, 5% SF)

Figure 4-15: Shrinkage versus Age for Concrete Containing
Different Dosage of SRA-G
(5% SF, 25% FA, 0.6% HRWR-G)

Figure 4-16: Shrinkage versus Age for Concrete Containing
Different Dosages of SRA-G
(5% SF, 25% FA, 0.4% HRWR-G, 0.2% LRWR-G)

Figure 4-17: Shrinkage versus Age for Concrete Containing Different Dosages of SRA-MB
(5% SF, 25% FA, 0.4% HRWR-MB, 0.2% LRWR-MB)

Figure 4-18: Shrinkage versus Age for Concrete Containing Different Cement Content with A/cm Ratio
(5% Metak, 25% FA, 0.4% HRWR-G, 0.2% LRWR-G)

Figure 4-19: Compressive Strength versus Age for Concrete with Different Dosages of Fly Ash and SRA-G (5% SF, 0.6% HRWR-G)

Figure 4-20: Compressive Strength versus Age for Concrete with Different Dosages of Fly Ash and SRA-G (5% Metak, 0.6% HRWR-G)

Figure 4-21: Compressive Strength versus Age for Concrete
with 20% Fly Ash
(0.6% HRWR-G)

Figure 4-22: Compressive Strength versus Age for Concrete
with 25% Fly Ash
(0.6% HRWR-G)

Figure 4-23: Compressive Strength versus Age for Concrete with 30% Fly Ash (0.6% HRWR-G)

Figure 4-24: Compressive Strength versus Age for Concrete with Different Dosages of HRWR-MB and LRWR-MB (25% FA, 5% SF)

Figure 4-25: Compressive Strength versus Age for Concrete with Different Dosages of SRA-G (5% SF, 25% FA, 0.6% HRWR-G)

Figure 4-26: Compressive Strength versus Age for Concrete with Different Dosages of SRA-G (5% SF, 25% FA, 0.4% HRWR-G, 0.2% LRWR-G)

Figure 4-27: Compressive Strength versus Age for Concrete
with Different Dosages of SRA-MB
(5% SF, 25% FA, 0.4% HRWR-MB, 0.2% LRWR-MB)

Figure 4-28: Compressive Strength versus Age for Concrete
with Different Cement Content and A/cm Ratio
(4 x 8-in. Cylinders)

Figure 4-29: Compressive Strength versus Age for Concrete
with Different Cement Content and A/cm Ratio
(6 x 12-in. Cylinders)

Chapter 5

Conclusions and Future Recommendations

5.1 Introduction

This chapter summarizes the conclusions on the effect of mineral and chemical admixtures on drying shrinkage and compressive strength of HSC. The conclusions are based on different concrete mixes and supplementary cement paste mixes. The mineral admixtures are used as follow: fly ash class F, silica fume, and metakaolin (calcine clay, class N). The chemical admixtures are used as follow: shrinkage reducing admixture, high-range water reducing admixture, low-range water reducing admixture, and delvo stabilizer.

5.2 Conclusions on Cement Paste

The following conclusions can be drawn on the effect of chemical and mineral admixtures on drying shrinkage of cement pastes.

- 1) The addition of SRA-G with dosage ranging from 0% to 2.5% reduces drying shrinkage. Furthermore, addition of SRA-G with dosage ranging from 1.5% to 2.5% has no significant effect on drying shrinkage.
- 2) The addition of SRA-MB with dosage ranging from 0% to 2.5% reduces drying shrinkage. Furthermore, addition of SRA-MB with dosage ranging from 1.5% to 2.5% has no significant effect on drying shrinkage.

- 3) The addition of HRWR-G with dosage ranging from 0% to 0.8% reduces drying shrinkage.
- 4) The addition of HRWR-MB with dosage ranging from 0% to 1% has no effect on drying shrinkage
- 5) The addition of LRWR-G with dosage ranging from 0% to 0.3% has no significant effect on drying shrinkage.
- 6) The addition of metakaolin with 0% to 30% replaced by weight of cementitious material has no significant effect on drying shrinkage.
- 7) The addition of silica fume with 0% to 30% replaced by weight of cementitious material increases drying shrinkage
- 8) The addition of fly ash with 0% to 35% replaced by weight of cementitious material has no effect on drying shrinkage.
- 9) The addition of fly ash with 0% to 35% replaced by total weight of cementitious material with 5% metakaolin and 0.2% HRWR-G has no effect on drying shrinkage. Furthermore, addition dosage of 1% SRA-G reduces drying shrinkage.
- 10) The addition of fly ash with 0% to 35% replaced by total weight of cementitious material with 5% silica fume and 0.2% HRWR-G has no effect on drying shrinkage. Furthermore, addition dosage of 2.5% SRA-G reduces drying shrinkage.
- 11) A summary of the effect of admixtures on drying shrinkage for cement paste mixes are given in Table 5-1. Each row in the table has two different mixes.

The two mixes are compared to each other and conclusion on the effect of adding admixture is summarized.

Table 5-1: The Effect of Admixtures on Drying Shrinkage of Cement Paste

Mix No.	w/cm	SRA G	HRWR G	LRWR G	SRA MB	HRWR MB	FA Class F	SF	METAK Class N	DELVO MB	Increase DS	Decrease DS	No Effect DS
1G	0.33	0											
8G	0.33	2.5										X	
1G	0.33		0										
5G	0.33		0.8									X	
3G	0.33	0	0.4										
11G	0.33	2.5	0.4									X	
12G	0.33			0									
15G	0.33			0.3									X
16G	0.33		0.4	0									
19G	0.33		0.4	0.3									X
18G	0.33	0	0.4	0.2									
24G	0.33	2.5	0.4	0.2								X	
2G	0.33		0.2						0				
37G	0.33		0.2						30				X
2G	0.33		0.2					0					
40G	0.33		0.2					30			X		
41G	0.33		0.2				0						
45G	0.33		0.2				35						X
25G	0.33		0.2				0		5				
29G	0.33		0.2				35		5				X
30G	0.33		0.2				0	5					
34G	0.33		0.2				35	5					X
46G	0.33	1	0.2				0		5				
50G	0.33	1	0.2				35		5			X	
51G	0.33	2.5	0.2				0	5					
55G	0.33	2.5	0.2				35	5				X	
56G	0.33					0							
60G	0.33					1							X
56G	0.33				0								
63G	0.33				2.5							X	
59G	0.33				0	0.6							
66G	0.33				2.5	0.6						X	
67G	0.4						20		5				
71G	0.6						20		5		X		
72G	0.4						20	5					
76G	0.6						20	5			X		
77G	0.33									0			
79G	0.33									0.2			X

5.2 Conclusions on HSC

The following conclusions can be drawn on the effect of chemical and mineral admixtures on drying shrinkage and compressive strength of HSC.

- 1) The addition of SRA-G with dosage ranging from 0% to 2.5% reduces drying shrinkage. Furthermore, addition of SRA-G with dosage ranging from 1.5% to 2.5% has no significant effect on drying shrinkage.
- 2) The addition of SRA-MB with dosage ranging from 0% to 2.5% reduces drying shrinkage. Furthermore, addition of SRA-MB with dosage ranging from 1.5% to 2.5% has no significant effect on drying shrinkage.
- 3) Fly ash replaced by total weight of cement at different percentage 20%, 25%, and 30% with 5% silica fume, and 0.6% HRWR-G has no significant effect on drying shrinkage.
- 4) Fly ash replaced by total weight of cement at different percentage 20%, 25%, and 30% with 5% silica fume, 0.6% HRWR-G, and 0.5% SRA-G does not affect drying shrinkage. Furthermore, addition dosage of 0.5% SRA-G reduces the drying shrinkage.
- 5) Fly ash replaced by total weight of cement at different percentage 20%, 25%, and 30% with 5% metakaolin and 0.6% HRWR-G has no significant effect on drying shrinkage.
- 6) Fly ash replaced by total weight of cement at different percentage 20%, 25%, and

30% with 5% metakaolin, 0.6% HRWR-G, and 0.5% SRA-G does not affect drying shrinkage. Furthermore, addition dosage of 0.5% SRA-G reduces the drying shrinkage.

- 7) The effect of 0.6% HRWR-MB on drying shrinkage is similar to the effect of 0.4% HRWR-MB + 0.2% LRWR-MB (no effect on drying shrinkage).
- 8) Different dosages of SRA-G with 0.6% HRWR-G reduces drying shrinkage.
- 9) Different dosages of SRA-G with 0.4% HRWR-G + 0.2% LRWR-G reduces drying shrinkage.
- 10) Different dosages of SRA-MB with 0.4% HRWR-MB + 0.2% LRWR-MB reduces drying shrinkage.
- 11) 0.6% HRWR-MB decrease compressive strength same as 0.4% HRWR-MB + 0.2% LRWR-MB; however, 0.6% HRWR-G increases compressive strength more than 0.4% HRWR-G + 0.2% LRWR-G.
- 12) A summary of the effect of admixtures on drying shrinkage and compressive strength for HSC is given in Table 5-2. Each row in the table has two different mixes. The two mixes are compared to each other and conclusion on the effect of adding admixture is summarized.

Table 5-2: The Effect of Admixtures on Drying Shrinkage & Compressive Strength of HSC

Mix No.	w/cm	SRA G	HRWR G	LRWR G	SRA MB	HRWR MB	LRWR MB	FA Class F	SF Class N	METAK Class N	A/cm	Increase DS	Decrease DS	NO DS	Increase CS	Decrease CS
2C	0.33		0.6					20	5			---	---	---	---	---
9C	0.33		0.6					30	5			---	---	X	---	X
3C	0.33		0.6					20		5		---	---	---	---	---
10C	0.33		0.6					30		5		---	---	X	---	X
1C	0.33	0.5	0.6					20	5			---	---	---	---	---
12C	0.33	0.5	0.6					30	5			---	---	X	---	X
4C	0.33	0.5	0.6					20		5		---	---	---	---	---
11C	0.33	0.5	0.6					30		5		---	---	X	---	X
2C	0.33	0	0.6					20	5			---	---	---	---	---
1C	0.33	0.5	0.6					20	5			---	X	---	---	X
5C	0.33	0	0.6					25	5			---	---	---	---	---
7C	0.33	0.5	0.6					25	5			---	X	---	---	X
9C	0.33	0	0.6					30	5			---	---	---	---	---
12C	0.33	0.5	0.6					30	5			---	X	---	---	---
3C	0.33	0	0.6					20		5		---	---	---	---	---
4C	0.33	0.5	0.6					20		5		---	X	---	---	---
6C	0.33	0	0.6					25		5		---	---	---	---	---
8C	0.33	0.5	0.6					25		5		---	X	---	---	X
10C	0.33	0	0.6					30		5		---	---	---	---	---
11C	0.33	0.5	0.6					30		5		---	---	X	---	X
23C	0.33				0	0.6		25	5			---	---	---	---	---
24C	0.33				0.5	0.6		25	5			---	X	---	---	---
23C	0.33					0.6	0	25	5			---	---	---	---	---
25C	0.33					0.4	0.2	25	5			---	---	X	---	X
5C	0.33	0	0.6					25	5			---	---	---	---	---
16C	0.33	2.5	0.6					25	5			---	X	---	---	X
17C	0.33	0	0.4	0.2				25	5			---	---	---	---	---
22C	0.33	2.5	0.4	0.2				25	5			---	X	---	---	X
25C	0.33				0	0.4	0.2	25	5			---	---	---	---	---
30C	0.33				2.5	0.4	0.2	25	5			---	X	---	---	X
32C	0.33		0.4	0.2				25		5	4.76	---	---	---	---	---
31C	0.33		0.4	0.2				25		5	4.80	---	X	---	X	---

5.3 Future Recommendations

The effect of various types of admixtures on drying shrinkage and compressive strength of cement paste and high-strength concrete were studied in this investigation. Future studies on addition of fly ash at different percentage with different w/cm ratios, addition of metakaolin at different percentage with different w/cm ratios, and addition of slag at different percentage and w/cm ratios will be recommended.

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**Appendix I: Shrinkage and Expansion Data of Cement Paste Containing Cement
Type II (Initial Zero Reading at Seven Days after Curing)**

**Appendix I (a): Shrinkage and Expansion Data of Cement Paste Containing Cement
Type II (Initial Zero Reading at Seven Days after Curing)**

Mix No.	Cement content (gr)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)					
			Air-dried (Shrinkage)		Water-cured (Expansion)		Average (Expansion)	Average (Shrinkage)
1G	1000	0	0	0	0	0	0	0
		7	-800	-820	-----	-----	-----	-810
		28	-1500	-1590	-----	-----	-----	-1545
		56	-1840	-1920	-----	-----	-----	-1880
		90	-1930	-2030	-----	-----	-----	-1980
		180	-1850	-1950	-----	-----	-----	-1900
2G	1000	0	0	0	0	0	0	0
		7	-900	-910	-----	-----	-----	-905
		28	-1690	-1660	-----	-----	-----	-1675
		56	-2010	-1940	-----	-----	-----	-1975
		90	-2030	-2010	-----	-----	-----	-2020
		180	-1990	-1930	-----	-----	-----	-1960
3G	1000	0	0	0	0	0	0	0
		7	-790	-----	-----	-----	-----	-790
		28	-1420	-----	-----	-----	-----	-1420
		56	-1690	-----	-----	-----	-----	-1690
		90	-1730	-----	-----	-----	-----	-1730
		180	-1730	-----	-----	-----	-----	-1730
4G	1000	0	0	0	0	0	0	0
		7	-940	-950	-----	-----	-----	-945
		28	-1640	-1670	-----	-----	-----	-1655
		56	-1880	-1910	-----	-----	-----	-1895
		90	-2030	-2080	-----	-----	-----	-2055
		180	-1980	-2000	-----	-----	-----	-1990
5G	1000	0	0	0	0	0	0	0
		7	-870	-850	-----	-----	-----	-860
		28	-1380	-1330	-----	-----	-----	-1355
		56	-1610	-1560	-----	-----	-----	-1585
		90	-1600	-1570	-----	-----	-----	-1585
		180	-1590	-1540	-----	-----	-----	-1565
6G	1000	0	0	0	0	0	0	0
		7	-760	-710	-----	-----	-----	-735
		28	-1170	-1090	-----	-----	-----	-1130
		56	-1240	-1320	-----	-----	-----	-1280
		90	-1430	-1470	-----	-----	-----	-1450
		180	-1570	-1450	-----	-----	-----	-1510
7G	1000	0	0	0	0	0	0	0
		7	-560	-550	-----	-----	-----	-555
		28	-910	-920	-----	-----	-----	-915
		56	-1120	-1150	-----	-----	-----	-1135
		90	-1270	-1280	-----	-----	-----	-1275
		180	-1230	-1250	-----	-----	-----	-1240

**Appendix I (b): Shrinkage and Expansion Data of Cement Paste Containing Cement
Type II (Initial Zero Reading at Seven Days after Curing)**

Mix No.	Cement content (gr)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)					
			Air-dried (Shrinkage)		Water-cured (Expansion)		Average (Expansion)	Average (Shrinkage)
8G	1000	0	0	0	0	0	0	0
		7	-470	-470	-470	-470	-470	-470
		21	-870	-870	-870	-870	-870	-870
		56	-1190	-1190	-1190	-1190	-1190	-1190
		90	-1320	-1320	-1320	-1320	-1320	-1320
		180	-1310	-1310	-1310	-1310	-1310	-1310
9G	1000	0	0	0	0	0	0	0
		7	-890	-880	-890	-890	-890	-885
		28	-1310	-1330	-1310	-1310	-1310	-1320
		56	-1660	-1370	-1660	-1660	-1660	-1665
		90	-1750	-1750	-1750	-1750	-1750	-1750
		180	-1710	-1700	-1710	-1710	-1710	-1705
10G	1000	0	0	0	0	0	0	0
		7	-560	-560	-560	-560	-560	-560
		28	-1100	-1110	-1100	-1100	-1100	-1105
		56	-1390	-1410	-1390	-1390	-1390	-1400
		90	-1560	-1570	-1560	-1560	-1560	-1565
		180	-1680	-1720	-1680	-1680	-1680	-1700
11G	1000	0	0	0	0	0	0	0
		7	-600	-620	-600	-600	-600	-610
		28	-910	-920	-910	-910	-910	-915
		56	-1160	-1140	-1160	-1160	-1160	-1150
		90	-1200	-1180	-1200	-1200	-1200	-1190
		180	-1190	-1170	-1190	-1190	-1190	-1180
12G	1000	0	0	0	0	0	0	0
		7	-1020	-1060	-1020	-1020	-1020	-1040
		21	-1750	-1680	-1750	-1750	-1750	-1715
		56	-2230	-2120	-2230	-2230	-2230	-2175
		90	-2350	-2250	-2350	-2350	-2350	-2300
		180	-2260	-2160	-2260	-2260	-2260	-2210
13G	1000	0	0	0	0	0	0	0
		7	-1080	-1100	-1080	-1080	-1080	-1090
		28	-1940	-1980	-1940	-1940	-1940	-1960
		56	-2340	-2390	-2340	-2340	-2340	-2365
		90	-2380	-2430	-2380	-2380	-2380	-2405
		180	-2270	-2310	-2270	-2270	-2270	-2290
14G	1000	0	0	0	0	0	0	0
		7	-1140	-1150	-1140	-1140	-1140	-1145
		28	-1990	-2000	-1990	-1990	-1990	-1995
		56	-2410	-2440	-2410	-2410	-2410	-2425
		90	-2440	-2460	-2440	-2440	-2440	-2450
		180	-2310	-2320	-2310	-2310	-2310	-2315

**Appendix I (c): Shrinkage and Expansion Data of Cement Paste Containing Cement
Type II (Initial Zero Reading at Seven Days after Curing)**

Mix No.	Cement content (gr)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)					
			Air-dried (Shrinkage)		Water-cured (Expansion)		Average (Expansion)	Average (Shrinkage)
15G	1000	0	0	0	0	0	0	0
		7	-1100	-1110	-----	-----	-----	-1105
		21	-1870	-1860	-----	-----	-----	-1865
		56	-2270	-2300	-----	-----	-----	-2285
		90	-2400	-2410	-----	-----	-----	-2405
		180	-2300	-2330	-----	-----	-----	-2315
16G	1000	0	0	0	0	0	0	0
		7	-1020	-1020	-----	-----	-----	-1020
		21	-1670	-1720	-----	-----	-----	-1695
		56	-2140	-2160	-----	-----	-----	-2150
		90	-2260	-2290	-----	-----	-----	-2275
		180	-2190	-2220	-----	-----	-----	-2205
17G	1000	0	0	0	0	0	0	0
		7	-1190	-----	-----	-----	-----	-1190
		28	-1640	-----	-----	-----	-----	-1640
		56	-2250	-----	-----	-----	-----	-2250
		90	-2340	-----	-----	-----	-----	-2340
		180	-2280	-----	-----	-----	-----	-2280
18G	1000	0	0	0	0	0	0	0
		7	-1230	-----	-----	-----	-----	-1230
		28	-1960	-----	-----	-----	-----	-1960
		56	-2420	-----	-----	-----	-----	-2420
		90	-2470	-----	-----	-----	-----	-2470
		180	-2360	-----	-----	-----	-----	-2360
19G	1000	0	0	0	0	0	0	0
		7	-1060	-1330	-----	-----	-----	-1195
		28	-1820	-2060	-----	-----	-----	-1940
		56	-2260	-2500	-----	-----	-----	-2380
		90	-2330	-2570	-----	-----	-----	-2450
		180	-2220	-2440	-----	-----	-----	-2330
20G	1000	0	0	0	0	0	0	0
		7	-950	-920	-----	-----	-----	-935
		28	-1580	-1530	-----	-----	-----	-1555
		56	-1920	-1900	-----	-----	-----	-1910
		90	-2000	-1990	-----	-----	-----	-1995
		180	-1950	-1900	-----	-----	-----	-1925
21G	1000	0	0	0	0	0	0	0
		7	-720	-710	-----	-----	-----	-715
		28	-1390	-1370	-----	-----	-----	-1380
		56	-1720	-1700	-----	-----	-----	-1710
		90	-1820	-1830	-----	-----	-----	-1825
		180	-1990	-1960	-----	-----	-----	-1975

**Appendix I (d): Shrinkage and Expansion Data of Cement Paste Containing Cement
Type II (Initial Zero Reading at Seven Days after Curing)**

Mix No.	Cement Content (gr)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)					
			Air-Dried (Shrinkage)		Water-Cured (Expansion)		Average (Expansion)	Average (Shrinkage)
22G	1000	0	0	0	0	0	0	0
		7	-600	-620				-610
		28	-1100	-1110				-1105
		56	-1300	-1340				-1320
		90	-1460	-1500				-1480
		180	-1420	-1460				-1440
23G	1000	0	0	0	0	0	0	0
		7	-490	-530				-510
		21	-900	-940				-920
		56	-1210	-1260				-1235
		90	-1350	-1410				-1380
		180	-1350	-1410				-1380
24G	1000	0	0	0	0	0	0	0
		7	-570	-570				-570
		28	-1010	-1020				-1015
		56	-1180	-1210				-1195
		90	-1310	-1310				-1310
		180						
25G	1000	0	0	0	0	0	0	0
		7	-1040	-1020				-1030
		28	-1640	-1610				-1625
		56	-1810	-1780				-1795
		90	-1930	-1890				-1910
		180	-1810	-1810				-1810
26G	1000	0	0	0	0	0	0	0
		7	-1240	-1280				-1260
		28	-1910	-1950				-1930
		56	-2060	-2070				-2065
		90	-2120	-2120				-2120
		180						
27G	1000	0	0	0	0	0	0	0
		7	-1290	-1300				-1295
		28	-1940	-1950				-1945
		56	-2000	-1990				-1995
		90	-2090	-2060				-2075
		180						
28G	1000	0	0	0	0	0	0	0
		7	-1260	-1220				-1240
		28	-1950	-1800				-1875
		56	-2060	-1990				-2025
		90	-2050	-2010				-2030
		180	-1920	-1860				-1890

**Appendix I (e): Shrinkage and Expansion Data of Cement Paste Containing Cement
Type II (Initial Zero Reading at Seven Days after Curing)**

Mix No.	Cement content (gr)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)					
			Air-dried (Shrinkage)		Water-cured (Expansion)		Average (Expansion)	Average (Shrinkage)
29G	1000	0	0	0	0	0	0	0
		7	-1220	-1280				-1250
		28	-1850	-1890				-1870
		56	-1990	-2060				-2025
		90	-2010	-2050				-2030
		180	-1850	-1890				-1870
30G	1000	0	0	0	0	0	0	0
		7	-1050	-1070				-1060
		28	-1880	-1890				-1885
		56	-2140	-2170				-2165
		90	-2250	-2290				-2270
		180	-2230	-2230				-2230
31 G	1000	0	0	0	0	0	0	0
		7	-1220	-1260				-1240
		28	-2060	-2090				-2075
		56	-2330	-2360				-2345
		90	-2420	-2440				-2430
		180	-2290	-2290				-2290
32G	1000	0	0	0	0	0	0	0
		7	-1270	-1250				-1260
		28	-2133	-2090				-2112
		56	-2360	-2330				-2345
		90	-2440	-2400				-2420
		180	-2320	-2250				-2285
33G	1000	0	0	0	0	0	0	0
		7	-1270	-1320				-1295
		28	-2150	-2140				-2145
		56	-2380	-2360				-2370
		90	-2430	-2400				-2415
		180	-2280	-2260				-2270
34G	1000	0	0	0	0	0	0	0
		7	-1360	-1270				-1315
		28	-2110	-2110				-2110
		56	-2270	-2270				-2270
		90	-2340	-2340				-2340
		180	-2160	-2200				-2180
35G	1000	0	0	0	0	0	0	0
		7	-1100	-1090				-1095
		21	-1610	-1620				-1615
		56	-1840	-1870				-1855
		90	-1940	-1950				-1945
		180	-1820	-1850				-1835

**Appendix I (f): Shrinkage and Expansion Data of Cement Paste Containing Cement
Type II (Initial Zero Reading at Seven Days after Curing)**

Mix No.	Cement content (gr)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)					
			Air-dried (Shrinkage)		Water-cured (Expansion)		Average (Expansion)	Average (Shrinkage)
36G	1000	0	0	0	0	0	0	0
		7	-1230	-1220				-1225
		21	-1690	-1670				-1680
		56	-1910	-1870				-1890
		90	-1960	-1960				-1960
		180	-1850	-1830				-1840
37G	1000	0	0	0	0	0	0	0
		7	-1340	-1350				-1345
		21	-1790	-1800				-1795
		56	-1990	-1960				-1975
		90	-2010	-2010				-2010
		180	-1830	-1820				-1825
38G	1000	0	0	0	0	0	0	0
		7	-1130	-1130				-1130
		21	-1890	-1890				-1890
		56	-2380	-2380				-2380
		90	-2550	-2550				-2550
		180	-2470	-2470				-2470
39G	1000	0	0	0	0	0	0	0
		7	-1090	-1210				-1150
		21	-1970	-2080				-2025
		56	-2590	-2660				-2625
		90	-2820	-2910				-2865
		180	-2760	-2830				-2795
40G	1000	0	0	0	0	0	0	0
		7	-1360					-1360
		21	-2290					-2290
		56	-2980					-2980
		90	-3250					-3250
		180	-3210					-3210
41G	1000	0	0	0	0	0	0	0
		7	-1080	-1040				-1060
		28	-1840	-1800				-1820
		56	-2150	-2080				-2115
		90	-2280	-2220				-2250
		180	-2110	-2070				-2090
42G	1000	0	0	0	0	0	0	0
		7	-1090	-1180				-1135
		28	-1920	-2000				-1960
		56	-2170	-2250				-2210
		90	-2270	-2360				-2315
		180	-2060	-2140				-2100

**Appendix I (g): Shrinkage and Expansion Data of Cement Paste Containing Cement
Type II (Initial Zero Reading at Seven Days after Curing)**

Mix No.	Cement content (gr)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)					
			Air-dried (Shrinkage)		Water-cured (Expansion)		Average (Expansion)	Average (Shrinkage)
43G	1000	0	0	0	0	0	0	0
		7	-1150	-1160				-1155
		28	-1980	-1970				-1975
		56	-2190	-2230				-2210
		90	-2310	-2330				-2320
		180	-2080	-2060				-2070
44G	1000	0	0	0	0	0	0	0
		7	-1120	-1130				-1125
		28	-1950	-1980				-1965
		56	-2200	-2190				-2195
		90	-2310	-2290				-2300
		180	-2080	-2080				-2080
45G	1000	0	0	0	0	0	0	0
		7	-1100	-1140				-1120
		28	-1920	-1940				-1930
		56	-2110	-2140				-2125
		90	-2210	-2240				-2225
		180	-1990	-2040				-2015
46G	1000	0	0	0	0	0	0	0
		7	-650	-600				-625
		28	-1110	-1090				-1100
		56	-1200	-1200				-1200
		90	-1390	-1340				-1365
		180	-1340	-1300				-1320
47G	1000	0	0	0	0	0	0	0
		7	-700	-650				-675
		28	-1260	-1190				-1225
		56	-1380	-1270				-1325
		90	-1480	-1410				-1445
		180	-1360	-1290				-1325
48G	1000	0	0	0	0	0	0	0
		7	-770	-700				-735
		28	-1240	-1200				-1220
		56	-1360	-1320				-1340
		90	-1460	-1410				-1435
		180	-1490	-1410				-1450
49G	1000	0	0	0	0	0	0	0
		7	-760	-780				-770
		28	-1320	-1300				-1310
		56	-1490	-1500				-1495
		90	-1510	-1540				-1525
		180	-1510	-1560				-1535

**Appendix I (h): Shrinkage and Expansion Data of Cement Paste Containing Cement
Type II (Initial Zero Reading at Seven Days after Curing)**

Mix No.	Cement content (gr)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)					
			Air-dried (Shrinkage)		Water-cured (Expansion)		Average (Expansion)	Average (Shrinkage)
50G	1000	0	0	0	0	0	0	0
		7	-860	-840	-----	-----	-----	-850
		28	-1380	-1370	-----	-----	-----	-1375
		56	-1560	-1520	-----	-----	-----	-1540
		90	-1590	-1520	-----	-----	-----	-1555
		180	-1610	-1540	-----	-----	-----	-1575
51G	1000	0	0	0	0	0	0	0
		7	-550	-540	-----	-----	-----	-545
		28	-950	-930	-----	-----	-----	-940
		56	-1180	-1170	-----	-----	-----	-1175
		90	-1290	-1250	-----	-----	-----	-1270
		180	-1390	-1370	-----	-----	-----	-1380
52G	1000	0	0	0	0	0	0	0
		7	-560	-530	-----	-----	-----	-545
		28	-1050	-960	-----	-----	-----	-1005
		56	-1280	-1210	-----	-----	-----	-1245
		90	-1410	-1340	-----	-----	-----	-1375
		180	-1460	-1400	-----	-----	-----	-1430
53G	1000	0	0	0	0	0	0	0
		7	-560	-570	-----	-----	-----	-565
		28	-1040	-980	-----	-----	-----	-1010
		56	-1240	-1260	-----	-----	-----	-1250
		90	-1400	-1430	-----	-----	-----	-1415
		180	-1460	-1470	-----	-----	-----	-1465
54G	1000	0	0	0	0	0	0	0
		7	-610	-590	-----	-----	-----	-600
		28	-1040	-1030	-----	-----	-----	-1035
		56	-1310	-1320	-----	-----	-----	-1315
		90	-1400	-1450	-----	-----	-----	-1425
		180	-1440	-1470	-----	-----	-----	-1455
55G	1000	0	0	0	0	0	0	0
		7	-690	-740	-----	-----	-----	-715
		28	-1060	-1090	-----	-----	-----	-1075
		56	-1330	-1340	-----	-----	-----	-1335
		90	-1470	-1470	-----	-----	-----	-1470
		180	-1490	-1490	-----	-----	-----	-1490
56G	1000	0	0	0	0	0	0	0
		7	-1170	-1150	-----	-----	-----	-1160
		28	-1810	-1850	-----	-----	-----	-1830
		56	-2180	-2160	-----	-----	-----	-2170
		90	-2270	-2260	-----	-----	-----	-2265
		180	-2340	-2330	-----	-----	-----	-2335

**Appendix I (i): Shrinkage and Expansion Data of Cement Paste Containing Cement
Type II (Initial Zero Reading at Seven Days after Curing)**

Mix No.	Cement content (gr)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)					
			Air-dried (Shrinkage)		Water-cured (Expansion)		Average (Expansion)	Average (Shrinkage)
57G	1000	0	0	0	0	0	0	0
		7	-1200	-1240				-1220
		28	-1870	-1930				-1900
		56	-2260	-2280				-2270
		90	-2340	-2370				-2355
		180	-2410	-2420				-2415
58G	1000	0	0	0	0	0	0	0
		7	-1210	-1200				-1205
		28	-1880	-1860				-1870
		56	-2260	-2230				-2245
		90	-2400	-2340				-2370
		180	-2450	-2400				-2425
59G	1000	0	0	0	0	0	0	0
		7	-1170	-1170				-1170
		28	-1820	-1820				-1820
		56	-2220	-2220				-2220
		90	-2360	-2350				-2355
		180		-2420				-2420
60G	1000	0	0	0	0	0	0	0
		7	-1270	-1270				-1270
		28	-1880	-1840				-1860
		56	-2220	-2140				-2180
		90	-2350	-2280				-2315
		180	-2390					-2390
61G	1000	0	0	0	0	0	0	0
		7	-860	-800				-840
		28	-1310	-1260				-1285
		56	-1550	-1520				-1535
		90	-1640	-1620				-1630
		180	-1710	-1700				-1705
62G	1000	0	0	0	0	0	0	0
		7	-670	-670				-670
		28	-1090	-1060				-1075
		56	-1340	-1280				-1310
		90	-1410	-1370				-1390
		180	-1500	-1470				-1485
63G	1000	0	0	0	0	0	0	0
		7	-660	-660				-660
		28	-950	-980				-965
		56	-1210	-1210				-1210
		90	-1300	-1310				-1305
		180	-1370	-1390				-1380

**Appendix I (j): Shrinkage and Expansion Data of Cement Paste Containing Cement
Type II (Initial Zero Reading at Seven Days after Curing)**

Mix No.	Cement content (gr)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)					
			Air-dried (Shrinkage)		Water-cured (Expansion)		Average (Expansion)	Average (Shrinkage)
64G	1000	0	0	0	0	0	0	0
		7	-780	-710				-745
		28	-1270	-1200				-1235
		56	-1480	-1440				-1460
		90	-1590	-1530				-1560
		180	-1700	-1640				-1670
65G	1000	0	0	0	0	0	0	0
		7	-690	-670				-680
		28	-1120	-1070				-1095
		56	-1340	-1310				-1325
		90	-1440	-1390				-1415
		180	-1540	-1510				-1525
66G	1000	0	0	0	0	0	0	0
		7	-640					-640
		28	-1010					-1010
		56	-1270					-1270
		90	-1340					-1340
		180	-1440					-1440
67G	1000	0	0	0	0	0	0	0
		7	-1390	-1410				-1400
		28	-2100	-2080				-2090
		56	-2360	-2380				-2370
		90	-2220	-2250				-2235
		180	-2280	-2330				-2305
68G	1000	0	0	0	0	0	0	0
		7	-1830	-1790				-1810
		28	-2490	-2430				-2460
		56	-2680	-2660				-2670
		90	-2520	-2510				-2515
		180	-2590	-2560				-2575
69G	1000	0	0	0	0	0	0	0
		7	-1760	-1790				-1775
		28	-2590	-2580				-2585
		56	-2760	-2750				-2755
		90	-2720	-2740				-2730
		180	-2780	-2770				-2775
70G	1000	0	0	0	0	0	0	0
		7	-1960	-1960				-1960
		28	-2840	-2830				-2835
		56	-2970	-2980				-2975
		90	-2980	-3070				-3025
		180	-3140	-3240				-3190

**Appendix I (k): Shrinkage and Expansion Data of Cement Paste Containing Cement
Type II (Initial Zero Reading at Seven Days after Curing)**

Mix No.	Cement content (gr)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)					
			Air-dried (Shrinkage)		Water-cured (Expansion)		Average (Expansion)	Average (Shrinkage)
71G	1000	0	0	0	0	0	0	0
		7	-2250	-2160	-----	-----	-----	-2205
		28	-3230	-3060	-----	-----	-----	-3145
		56	-3470	-3290	-----	-----	-----	-3380
		90	-3710	-3500	-----	-----	-----	-3605
		180	-4210	-3890	-----	-----	-----	-4050
72G	1000	0	0	0	0	0	0	0
		7	-1480	-1450	-----	-----	-----	-1465
		28	-2550	-2540	-----	-----	-----	-2545
		56	-2880	-2860	-----	-----	-----	-2870
		90	-2830	-2850	-----	-----	-----	-2840
		180	-2920	-2880	-----	-----	-----	-2900
73G	1000	0	0	0	0	0	0	0
		7	-1620	-1590	-----	-----	-----	-1605
		28	-2730	-2680	-----	-----	-----	-2705
		56	-3010	-2930	-----	-----	-----	-2970
		90	-3050	-2940	-----	-----	-----	-2995
		180	-3130	-3010	-----	-----	-----	-3070
74G	1000	0	0	0	0	0	0	0
		7	-1570	-1620	-----	-----	-----	-1595
		28	-2720	-2760	-----	-----	-----	-2740
		56	-2980	-3050	-----	-----	-----	-3015
		90	-3050	-3110	-----	-----	-----	-3080
		180	-3130	-3200	-----	-----	-----	-3165
75G	1000	0	0	0	0	0	0	0
		7	-1870	-1880	-----	-----	-----	-1875
		28	-3050	-3080	-----	-----	-----	-3065
		56	-3360	-3430	-----	-----	-----	-3395
		90	-3490	-3620	-----	-----	-----	-3555
		180	-3710	-3920	-----	-----	-----	-3815
76G	1000	0	0	0	0	0	0	0
		7	-1990	-2020	-----	-----	-----	-2005
		28	-3220	-3240	-----	-----	-----	-3230
		56	-3710	-3810	-----	-----	-----	-3760
		90	-4190	-4330	-----	-----	-----	-4260
		180	-4820	-5050	-----	-----	-----	-4935
77G	1000	0	0	0	0	0	0	0
		7	-1030	-1040	-----	-----	-----	-1035
		28	-1700	-1690	-----	-----	-----	-1695
		56	-1900	-1870	-----	-----	-----	-1885
		90	-1950	-1950	-----	-----	-----	-1950
		180	-2190	-2170	-----	-----	-----	-2180

**Appendix I (I): Shrinkage and Expansion Data of Cement Paste Containing Cement
Type II (Initial Zero Reading at Seven Days after Curing)**

Mix No.	Cement content (gr)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)					
			Air-dried (Shrinkage)		Water-cured (Expansion)		Average (Expansion)	Average (Shrinkage)
78G	1000	0	0	0	0	0	0	0
		7	-1040	-1060				-1050
		28	-1710	-1690				-1700
		56	-1950	-1960				-1955
		90	-1990	-1980				-1985
		180	-2220	-2220				-2220
79G	1000	0	0	0	0	0	0	0
		7	-970	-1070				-1020
		28	-1680	-1770				-1725
		56	-1940	-2000				-1970
		90	-1980	-2030				-2005
		180	-2230	-2280				-2290
80G	1000	0	0	0	0	0	0	0
		7	-1450	-1540				-1495
		28	-2690	-2780				-2735
		56	-2690	-2860				-2775
		90	-2700	-2820				-2760
		180	-3070	-3290				-3180
81G	1000	0	0	0	0	0	0	0
		7	-1260	-1290				-1275
		28	-2350	-2340				-2345
		56	-2500	-2460				-2480
		90	-2490	-2460				-2475
		180	-2190	-2170				-2180

Appendix I: Mix No. 1G

Shrinkage of cement paste initial zero reading at seven days after curing

Mix No. 2G

Shrinkage of cement paste initial zero reading at seven days after curing

Mix No. 3G

Shrinkage of cement paste initial zero reading at seven days after curing

Appendix I: Mix No. 4G
 Shrinkage of cement paste initial zero reading at seven
 days after curing

Mix No. 5G
 Shrinkage of cement paste initial zero reading at seven
 days after curing

Mix No. 6G
 Shrinkage of cement paste initial zero reading at seven
 days after curing

Appendix I: Mix No. 7G

Shrinkage of cement paste initial zero reading at seven days after curing

Mix No. 8G

Shrinkage of cement paste initial zero reading at seven days after curing

Mix No. 9G

Shrinkage of cement paste initial zero reading at seven days after curing

Appendix I: Mix No. 10G
Shrinkage of cement paste initial zero reading at seven
days after curing

Mix No. 11G
Shrinkage of cement paste initial zero reading at seven
days after curing

Mix No. 12G
Shrinkage of cement paste initial zero reading at seven
days after curing

Appendix I: Mix No. 13G

Shrinkage of cement paste initial zero reading at seven days after curing

Mix No. 14G

Shrinkage of cement paste initial zero reading at seven days after curing

Mix No. 15G

Shrinkage of cement paste initial zero reading at seven days after curing

Appendix I: Mix No. 16G

Shrinkage of cement paste initial zero reading at seven days after curing

Mix No. 17G

Shrinkage of cement paste initial zero reading at seven days after curing

Mix No.18G

Shrinkage of cement paste initial zero reading at seven days after curing

Appendix I: Mix No.19G

Shrinkage of cement paste initial zero reading at seven days after curing

Mix No. 20G

Shrinkage of cement paste initial zero reading at seven days after curing

Mix No. 21G

Shrinkage of cement paste initial zero reading at seven days after curing

Appendix I: Mix No. 22G
 Shrinkage of cement paste initial zero reading at seven
 days after curing

Mix No. 23G
 Shrinkage of cement paste initial zero reading at seven
 days after curing

Mix No. 24G
 Shrinkage of cement paste initial zero reading after seven
 days of curing

Appendix I: Mix No. 25G
Shrinkage of cement paste initial zero reading at seven
days after curing

Mix No. 26G
Shrinkage of cement paste initial zero reading at seven
days after curing

Mix No. 27G
Shrinkage of cement paste initial zero reading at seven
days after curing

Appendix I: Mix No. 28G
Shrinkage of cement paste initial zero reading at seven
days after curing

Mix No. 29G
Shrinkage of cement paste initial zero reading at seven
days after curing

Mix No. 30G
Shrinkage of cement paste initial zero reading at seven
days after curing

Appendix I: Mix No. 31G
Shrinkage of cement paste initial zero reading at seven
days after curing

Mix No. 32G
Shrinkage of cement paste initial zero reading at seven
days after curing

Mix No. 33G
Shrinkage of cement paste initial zero reading at seven
days after curing

Appendix I: Mix No. 34G
Shrinkage of cement paste initial zero reading at seven
days after curing

Mix No. 35G
Shrinkage of cement paste initial zero reading at seven
days after curing

Mix No. 36G
Shrinkage of cement paste initial zero reading at seven
days after curing

Appendix I: Mix No.37G
 Shrinkage of cement paste initial zero reading at seven
 days after curing

Mix No. 38G
 Shrinkage of cement paste initial zero reading at seven
 days after curing

Mix No. 39G
 Shrinkage of cement paste initial zero reading at seven
 days after curing

Appendix I: Mix No. 40G

Shrinkage of cement paste initial zero reading at seven days after curing

Mix No. 41G

Shrinkage of cement paste initial zero reading at seven days after curing

Mix No. 42G

Shrinkage of cement paste initial zero reading at seven days after curing

Appendix I: Mix No. 43G
 Shrinkage of cement paste initial zero reading at seven
 days after curing

Mix No. 44G
 Shrinkage of cement paste initial zero reading at seven
 days after curing

Mix No. 45G
 Shrinkage of cement paste initial zero reading at seven
 days after curing

Appendix I: Mix No. 46G

Shrinkage of cement paste initial zero reading at seven days after curing

Mix No. 47G

Shrinkage of cement paste initial zero reading at seven days after curing

Mix No. 48G

Shrinkage of cement paste initial zero reading at seven days after curing

Appendix I: Mix No. 49G

Shrinkage of cement paste initial zero reading at seven days after curing

Mix No. 50G

Shrinkage of cement paste initial zero reading at seven days after curing

Mix No. 51G

Shrinkage of cement paste initial zero reading at seven days after curing

Appendix I: Mix No. 52G
Shrinkage of cement paste initial zero reading at seven
days after curing

Mix No. 53G
Shrinkage of cement paste initial zero reading at seven
days after curing

Mix No. 54G
Shrinkage of cement paste initial zero reading at seven
days after curing

Appendix I: Mix No. 55G
Shrinkage of cement paste initial zero reading at seven
days after curing

Mix No. 56G
Shrinkage of cement paste initial zero reading at seven
days after curing

Mix No. 57G
Shrinkage of cement paste initial zero reading at seven
days after curing

Appendix I: Mix No. 58G
 Shrinkage of cement paste initial zero reading at seven
 days after curing

Mix No. 59G
 Shrinkage of cement paste initial zero reading at seven
 days after curing

Mix No. 60G
 Shrinkage of cement paste initial zero reading at seven
 days after curing

Appendix I: Mix No. 61G
 Shrinkage of cement paste initial zero reading at seven
 days after curing

Mix No. 62G
 Shrinkage of cement paste initial zero reading at seven
 days after curing

Mix No. 63G
 Shrinkage of cement paste initial zero reading at seven
 days after curing

Appendix I: Mix No. 64G

Shrinkage of cement paste initial zero reading at seven days after curing

Mix No. 65G

Shrinkage of cement paste initial zero reading at seven days after curing

Mix No. 66G

Shrinkage of cement paste initial zero reading at seven days after curing

Appendix I: Mix No. 67G

Shrinkage of cement paste initial zero reading at seven days after curing

Mix No. 68G

Shrinkage of cement paste initial zero reading at seven days after curing

Mix No. 69G

Shrinkage of cement paste initial zero reading at seven days after curing

Appendix I: Mix No. 70G
 Shrinkage of cement paste initial zero reading at seven
 days after curing

Mix No. 71G
 Shrinkage of cement paste initial zero reading at seven
 days after curing

Mix No. 72G
 Shrinkage of cement paste initial zero reading at seven
 days after curing

Appendix I: Mix No. 73G
Shrinkage of cement paste initial zero reading at seven
days after curing

Mix No. 74G
Shrinkage of cement paste initial zero reading at seven
days after curing

Mix No. 75G
Shrinkage of cement paste initial zero reading at seven
days after curing

Appendix I: Mix No. 76G

Shrinkage of cement paste initial zero reading at seven days after curing

Mix No. 77G

Shrinkage of cement paste initial zero reading after seven days of curing

Mix No. 78G

Shrinkage of cement paste initial zero reading at seven days after curing

Appendix I: Mix No. 79G

Shrinkage of cement paste initial zero reading at seven days after curing

Mix No. 80G

Shrinkage of cement paste initial zero reading at seven days after curing

Mix No. 81G

Shrinkage of cement paste initial zero reading at seven days after curing

**Appendix II: Shrinkage and Expansion Data of Cement Paste Containing Cement
Type II (Initial Reading Was Taken after One Day of Curing)**

**Appendix II (a): Shrinkage and Expansion Data of Cement Paste Containing Cement
Type II (Initial Reading Was Taken after One Day of Curing)**

Mix No.	Cement content (gr)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)					
			Air-dried (Shrinkage)		Water-cured (Expansion)		Average (Expansion)	Average (Shrinkage)
1G	1000	1	0	0	0	0	0	0
		7	----	----	300	320	310	----
		28	-1390	-1780	----	----	----	-1585
		56	-1790	-1860	----	----	----	-1825
		90	-1940	-2040	----	----	----	-1990
		180	-1850	-1950	----	----	----	-1900
2G	1000	1	0	0	0	0	0	0
		7	----	----	260	270	275	----
		28	-1580	-1540	----	----	----	-1560
		56	-1930	-1880	----	----	----	-1905
		90	-2050	-1990	----	----	----	-2020
		180	-1990	-1930	----	----	----	-1960
3G	1000	1	0	0	0	0	0	0
		7	----	----	280	----	280	----
		28	-1320	----	----	----	----	-1320
		56	-1650	----	----	----	----	-1650
		90	-1780	----	----	----	----	-1780
		180	-1730	----	----	----	----	-1730
4G	1000	1	0	0	0	0	0	0
		7	----	----	230	220	225	----
		28	-1220	-1260	----	----	----	-1240
		56	-1630	-1650	----	----	----	-1640
		90	-1750	-1810	----	----	----	-1780
		180	-1750	-1780	----	----	----	-1765
5G	1000	1	0	0	0	0	0	0
		7	----	----	210	160	185	----
		28	-1070	-1070	----	----	----	-1070
		56	-1280	-1340	----	----	----	-1310
		90	-1460	-1450	----	----	----	-1455
		180	-1380	-1380	----	----	----	-1380
6G	1000	1	0	0	0	0	0	0
		7	----	----	260	160	210	----
		28	-700	-870	----	----	----	-785
		56	-880	-1140	----	----	----	-1010
		90	-1080	-1290	----	----	----	-1185
		180	-1310	-1290	----	----	----	-1300
7G	1000	1	0	0	0	0	0	0
		7	----	----	150	180	165	----
		28	-700	-650	----	----	----	-675
		56	-910	-900	----	----	----	-905
		90	-1060	-1060	----	----	----	-1060
		180	-1080	-1070	----	----	----	-1075

**Appendix II (b): Shrinkage and Expansion Data of Cement Paste Containing Cement
Type II (Initial Reading Was Taken after One Day of Curing)**

Mix No.	Cement content (gr)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)					
			Air-dried (Shrinkage)		Water-cured (Expansion)		Average (Expansion)	Average (Shrinkage)
8G	1000	1	0	0	0	0	0	0
		7	----	----	270	----	270	----
		28	-600	----	----	----	----	-600
		56	-860	----	----	----	----	-860
		90	-1050	----	----	----	----	-1050
		180	-1030	----	----	----	----	-1030
9G	1000	1	0	0	0	0	0	0
		7	----	----	350	345	347	----
		28	-840	-835	----	----	----	-837
		56	-1240	-1265	----	----	----	-1252
		90	-1400	-1405	----	----	----	-1402
		180	-1380	-1395	----	----	----	-1387
10G	1000	1	0	0	0	0	0	0
		7	----	----	310	300	305	----
		28	-670	-670	----	----	----	-670
		56	-1040	-1080	----	----	----	-1060
		90	-1250	-1270	----	----	----	-1260
		180	-1370	-1410	----	----	----	-1390
11G	1000	1	0	0	0	0	0	0
		7	----	----	410	400	405	----
		28	-410	-420	----	----	----	-415
		56	-680	-700	----	----	----	-690
		90	-740	-790	----	----	----	-765
		180	-790	-810	----	----	----	-810
12G	1000	1	0	0	0	0	0	0
		7	----	----	340	280	310	----
		28	-1410	-1400	----	----	----	-1405
		56	-1820	-1790	----	----	----	-1805
		90	-1980	-1950	----	----	----	-1965
		180	-1920	-1880	----	----	----	-1900
13G	1000	1	0	0	0	0	0	0
		7	----	----	300	320	310	----
		28	-1430	-1450	----	----	----	-1440
		56	-1880	-1910	----	----	----	-1895
		90	-2170	-2170	----	----	----	-2170
		180	-2010	-2000	----	----	----	-2005
14G	1000	1	0	0	0	0	0	0
		7	----	----	310	310	310	----
		28	-1460	-1480	----	----	----	-1480
		56	-1910	-1970	----	----	----	-1940
		90	-2200	-2250	----	----	----	-2225
		180	-2050	-2060	----	----	----	-2055

**Appendix II (c): Shrinkage and Expansion Data of Cement Paste Containing Cement
Type II (Initial Reading Was Taken after One Day of Curing)**

Mix No.	Cement content (gr)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)					
			Air-dried (Shrinkage)		Water-cured (Expansion)		Average (Expansion)	Average (Shrinkage)
15G	1000	1	0	0	0	0	0	0
		7	-----	-----	440	460	450	-----
		28	-1430	-1400	-----	-----	-----	-1415
		56	-1790	-1810	-----	-----	-----	-1800
		90	-1930	-1940	-----	-----	-----	-1935
		180	-1860	-1870	-----	-----	-----	-1865
16G	1000	1	0	0	0	0	0	0
		7	-----	-----	320	350	335	-----
		28	-1350	-1370	-----	-----	-----	-1360
		56	-1770	-1770	-----	-----	-----	-1770
		90	-1930	-1930	-----	-----	-----	-1930
		180	-1870	-1870	-----	-----	-----	-1870
17G	1000	1	0	0	0	0	0	0
		7	-----	-----	290	-----	290	-----
		28	-1350	-----	-----	-----	-----	-1350
		56	-1960	-----	-----	-----	-----	-1960
		90	-2050	-----	-----	-----	-----	-2050
		180	-1990	-----	-----	-----	-----	-1990
18G	1000	1	0	0	0	0	0	0
		7	-----	-----	450	-----	450	-----
		28	-1260	-----	-----	-----	-----	-1260
		56	-1910	-----	-----	-----	-----	-1910
		90	-2000	-----	-----	-----	-----	-2000
		180	-1940	-----	-----	-----	-----	-1940
19G	1000	1	0	0	0	0	0	0
		7	-----	-----	270	470	370	-----
		28	-1280	1320	-----	-----	-----	-1300
		56	-1940	-1970	-----	-----	-----	-1955
		90	-2050	-2060	-----	-----	-----	-2055
		180	-1980	-2020	-----	-----	-----	-2000
20G	1000	1	0	0	0	0	0	0
		7	-----	-----	490	480	485	-----
		28	-870	-860	-----	-----	-----	-865
		56	-1380	-1350	-----	-----	-----	-1365
		90	-1500	-1510	-----	-----	-----	-1505
		180	-1470	-1450	-----	-----	-----	-1460
21G	1000	1	0	0	0	0	0	0
		7	-----	-----	410	390	400	-----
		28	-840	-870	-----	-----	-----	-855
		56	-1240	-1250	-----	-----	-----	-1245
		90	-1410	-1440	-----	-----	-----	-1425
		180	-1550	-1560	-----	-----	-----	-1555

**Appendix II (d): Shrinkage and Expansion Data of Cement Paste Containing Cement
Type II (Initial Reading Was Taken after One Day of Curing)**

Mix No.	Cement content (gr)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)					
			Air-dried (Shrinkage)		Water-cured (Expansion)		Average (Expansion)	Average (Shrinkage)
22G	1000	1	0	0	0	0	0	0
		7	----	----	610	630	620	----
		28	-350	-350	----	----	----	-350
		56	-670	-670	----	----	----	-670
		90	-790	-810	----	----	----	-800
		180	----	----	----	----	----	----
23G	1000	1	0	0	0	0	0	0
		7	----	----	530	630	580	----
		28	-370	-310	----	----	----	-340
		56	-650	-590	----	----	----	-620
		90	-800	-770	----	----	----	-785
		180	-790	-760	----	----	----	-775
24G	1000	1	0	0	0	0	0	0
		7	----	----	520	530	525	----
		28	-370	-420	----	----	----	-395
		56	-660	-640	----	----	----	-650
		90	-740	-760	----	----	----	-750
		180	----	----	----	----	----	----
25G	1000	1	0	0	0	0	0	0
		7	----	----	240	220	230	----
		28	-1270	-1230	----	----	----	-1250
		56	-1560	-1550	----	----	----	-1555
		90	-1650	-1620	----	----	----	-1635
		180	----	----	----	----	----	----
26G	1000	1	0	0	0	0	0	0
		7	----	----	250	260	255	----
		28	-1500	-1520	----	----	----	-1510
		56	-1810	-1820	----	----	----	-1815
		90	-1830	-1840	----	----	----	-1835
		180	----	----	----	----	----	----
27G	1000	1	0	0	0	0	0	0
		7	----	----	260	250	255	----
		28	-1570	-1530	----	----	----	-1550
		56	-1780	-1790	----	----	----	-1785
		90	-1790	-1770	----	----	----	-1780
		180	----	----	----	----	----	----
28G	1000	1	0	0	0	0	0	0
		7	----	----	190	140	165	----
		28	-1600	-1610	----	----	----	-1605
		56	-1850	-1830	----	----	----	-1840
		90	-1850	-1860	----	----	----	-1855
		180	----	----	----	----	----	----

**Appendix II (e): Shrinkage and Expansion Data of Cement Paste Containing Cement
Type II (Initial Reading Was Taken after One Day of Curing)**

Mix No.	Cement content (gr)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)					
			Air-dried (Shrinkage)		Water-cured (Expansion)		Average (Expansion)	Average (Shrinkage)
29G	1000	1	0	0	0	0	0	0
		7	-----	-----	170	180	175	-----
		28	-1660	-1690	-----	-----	-----	-1675
		56	-1800	-1850	-----	-----	-----	-1825
		90	-1820	-1870	-----	-----	-----	-1845
		180	-1660	-1690	-----	-----	-----	-1675
30G	1000	1	0	0	0	0	0	0
		7	-----	-----	310	310	310	-----
		28	-1380	-1370	-----	-----	-----	-1375
		56	-1830	-1780	-----	-----	-----	-1805
		90	-1920	-1950	-----	-----	-----	-1935
		180	-----	-----	-----	-----	-----	-----
31G	1000	1	0	0	0	0	0	0
		7	-----	-----	250	270	260	-----
		28	-1620	-1320	-----	-----	-----	-1620
		56	-2050	-2030	-----	-----	-----	-2040
		90	-2150	-2140	-----	-----	-----	-2145
		180	-2000	-1990	-----	-----	-----	-1995
32G	1000	1	0	0	0	0	0	0
		7	-----	-----	260	210	235	-----
		28	-1660	-1650	-----	-----	-----	-1655
		56	-2060	-2050	-----	-----	-----	-2055
		90	-2160	-2170	-----	-----	-----	-2165
		180	-----	-----	-----	-----	-----	-----
33G	1000	1	0	0	0	0	0	0
		7	-----	-----	160	180	170	-----
		28	-1770	-1750	-----	-----	-----	-1760
		56	-2160	-2130	-----	-----	-----	-2145
		90	-2260	-2220	-----	-----	-----	-2240
		180	-----	-----	-----	-----	-----	-----
34G	1000	1	0	0	0	0	0	0
		7	-----	-----	150	160	155	-----
		28	-1750	-1770	-----	-----	-----	-1760
		56	-2090	-2070	-----	-----	-----	-2080
		90	-2180	-2170	-----	-----	-----	-2175
		180	-2030	-2010	-----	-----	-----	-2020
35G	1000	1	0	0	0	0	0	0
		7	-----	-----	210	260	235	-----
		28	-1400	-1360	-----	-----	-----	-1380
		56	-1600	-1570	-----	-----	-----	-1585
		90	-1720	-1680	-----	-----	-----	-1700
		180	-1580	-1560	-----	-----	-----	-1600

Appendix II (f): Shrinkage and Expansion Data of Cement Paste Containing Cement Type II (Initial Reading Was Taken after One Day of Curing)

Mix No.	Cement content (gr)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)					
			Air-dried (Shrinkage)		Water-cured (Expansion)		Average (Expansion)	Average (Shrinkage)
36G	1000	1	0	0	0	0	0	0
		7	-----	-----	220	220	220	-----
		28	-1470	-1450	-----	-----	-----	-1460
		56	-1650	-1620	-----	-----	-----	-1635
		90	-1740	-1740	-----	-----	-----	-1740
		180	-----	-----	-----	-----	-----	-----
37G	1000	1	0	0	0	0	0	0
		7	-----	-----	230	230	230	-----
		28	-1560	-1570	-----	-----	-----	-1565
		56	-1720	-1730	-----	-----	-----	-1725
		90	-1770	-1770	-----	-----	-----	-1770
		180	-----	-----	-----	-----	-----	-----
38G	1000	1	0	0	0	0	0	0
		7	-----	-----	230	340	350	-----
		28	-1530	-1550	-----	-----	-----	-1540
		56	-1940	-1970	-----	-----	-----	-1955
		90	-2160	-2180	-----	-----	-----	-2170
		180	-----	-----	-----	-----	-----	-----
39G	1000	1	0	0	0	0	0	0
		7	-----	-----	370	480	425	-----
		28	-1600	-1600	-----	-----	-----	-1600
		56	-2140	-2080	-----	-----	-----	-2110
		90	-2410	-2390	-----	-----	-----	-2400
		180	-2390	-2350	-----	-----	-----	-2370
40G	1000	1	0	0	0	0	0	0
		7	-----	-----	560	-----	560	-----
		28	-1730	-----	-----	-----	-----	-1730
		56	-2340	-----	-----	-----	-----	-2340
		90	-2670	-----	-----	-----	-----	-2670
		180	-----	-----	-----	-----	-----	-----
41G	1000	1	0	0	0	0	0	0
		7	-----	-----	370	330	350	-----
		21	-1090	-1130	-----	-----	-----	-1110
		56	-1750	-1730	-----	-----	-----	-1740
		90	-1900	-1880	-----	-----	-----	-1890
		180	-1830	-1780	-----	-----	-----	-1805
42G	1000	1	0	0	0	0	0	0
		7	-----	-----	110	180	145	-----
		21	-1420	-1440	-----	-----	-----	-1430
		56	-2040	-2060	-----	-----	-----	-2050
		90	-2160	-2180	-----	-----	-----	-2170
		180	-2040	-2050	-----	-----	-----	-2045

**Appendix II (g): Shrinkage and Expansion Data of Cement Paste Containing Cement
Type II (Initial Reading Was Taken after One Day of Curing)**

Mix No.	Cement content (gr)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)					
			Air-dried (Shrinkage)		Water-cured (Expansion)		Average (Expansion)	Average (Shrinkage)
43G	1000	1	0	0	0	0	0	0
		7	-----	-----	190	190	190	-----
		21	-1370	-1410	-----	-----	-----	-1390
		56	-1980	-2030	-----	-----	-----	-2005
		90	-2110	-2140	-----	-----	-----	-2125
		180	-1990	-1990	-----	-----	-----	-1990
44G	1000	1	0	0	0	0	0	0
		7	-----	-----	160	150	155	-----
		21	-1430	-1440	-----	-----	-----	-1435
		56	-2030	-2030	-----	-----	-----	-2030
		90	-2140	-2130	-----	-----	-----	-2135
		180	-2000	-2010	-----	-----	-----	-2005
45G	1000	1	0	0	0	0	0	0
		7	-----	-----	90	150	120	-----
		21	-1500	-1450	-----	-----	-----	-1475
		56	-2030	-1990	-----	-----	-----	-2010
		90	-2120	-2080	-----	-----	-----	-2100
		180	-1980	-1920	-----	-----	-----	-1950
46G	1000	1	0	0	0	0	0	0
		7	-----	-----	280	260	270	-----
		21	-600	-570	-----	-----	-----	-585
		56	-910	-920	-----	-----	-----	-915
		90	-1040	-1060	-----	-----	-----	-1050
		180	-1070	-1060	-----	-----	-----	-1065
47G	1000	1	0	0	0	0	0	0
		7	-----	-----	170	160	165	-----
		21	-890	-800	-----	-----	-----	-845
		56	-1160	-1110	-----	-----	-----	-1135
		90	-1280	-1230	-----	-----	-----	-1255
		180	-1200	-1190	-----	-----	-----	-1195
48G	1000	1	0	0	0	0	0	0
		7	-----	-----	220	220	220	-----
		28	-940	-890	-----	-----	-----	-915
		56	-1130	-1080	-----	-----	-----	-1105
		90	-1240	-1190	-----	-----	-----	-1215
		180	-1270	-1190	-----	-----	-----	-1230
49G	1000	1	0	0	0	0	0	0
		7	-----	-----	210	200	205	-----
		28	-1020	-1010	-----	-----	-----	-1015
		56	-1220	-1250	-----	-----	-----	-1235
		90	-1340	-1370	-----	-----	-----	-1355
		180	-1300	-1360	-----	-----	-----	-1340

**Appendix II (h): Shrinkage and Expansion Data of Cement Paste Containing Cement
Type II (Initial Reading Was Taken after One Day of Curing)**

Mix No.	Cement content (gr)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)					
			Air-dried (Shrinkage)		Water-cured (Expansion)		Average (Expansion)	Average (Shrinkage)
50G	1000	1	0	0	0	0	0	0
		7	----	----	230	160	195	----
		28	-1050	-1110	----	----	----	-1080
		56	-1290	-1320	----	----	----	-1305
		90	-1380	-1400	----	----	----	-1390
		180	-1380	-1380	----	----	----	-1380
51G	1000	1	0	0	0	0	0	0
		7	----	----	420	410	415	----
		28	-450	-440	----	----	----	-445
		56	-680	-680	----	----	----	-680
		90	-870	-840	----	----	----	-855
		180	-970	-960	----	----	----	-965
52G	1000	1	0	0	0	0	0	0
		7	----	----	370	330	350	----
		28	-610	-590	----	----	----	-600
		56	-820	-790	----	----	----	-805
		90	-1040	-1010	----	----	----	-1025
		180	-1090	-1070	----	----	----	-1080
53G	1000	1	0	0	0	0	0	0
		7	----	----	350	330	340	----
		28	-610	-620	----	----	----	-615
		56	-820	-840	----	----	----	-830
		90	-1040	-1050	----	----	----	-1045
		180	-1110	-1140	----	----	----	-1125
54G	1000	1	0	0	0	0	0	0
		7	----	----	340	310	325	----
		28	-640	-670	----	----	----	-655
		56	-860	-890	----	----	----	-875
		90	-1060	-1140	----	----	----	-1100
		180	-1100	-1160	----	----	----	-1130
55G	1000	1	0	0	0	0	0	0
		7	----	----	320	310	315	----
		28	-650	-720	----	----	----	-685
		56	-970	-1030	----	----	----	-1000
		90	-1120	-1130	----	----	----	-1125
		180	-1160	-1160	----	----	----	-1160
56G	1000	1	0	0	0	0	0	0
		7	----	----	330	290	310	----
		28	-1270	-1370	----	----	----	-1320
		56	-1810	-1860	----	----	----	-1835
		90	-1890	-1950	----	----	----	-1920
		180	-2010	-2020	----	----	----	-2015

**Appendix II (i): Shrinkage and Expansion Data of Cement Paste Containing Cement
Type II (Initial Reading Was Taken after One Day of Curing)**

Mix No.	Cement content (gr)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)					
			Air-dried (Shrinkage)		Water-cured (Expansion)		Average (Expansion)	Average (Shrinkage)
57G	1000	1	0	0	0	0	0	0
		7	----	----	330	290	310	----
		28	-1360	-1430	----	----	----	-1395
		56	-1890	-1920	----	----	----	-1905
		90	-1980	-2040	----	----	----	-2010
		180	-2060	-2110	----	----	----	-2085
58G	1000	1	0	0	0	0	0	0
		7	----	----	310	300	305	----
		28	-1390	-1400	----	----	----	-1395
		56	-1910	-1910	----	----	----	-1910
		90	-2030	-2000	----	----	----	-2015
		180	-2130	-2110	----	----	----	-2120
59G	1000	1	0	0	0	0	0	0
		7	----	----	240	270	250	----
		28	-1420	-1380	----	----	----	-1400
		56	-1920	-1920	----	----	----	-1920
		90	-2080	-2060	----	----	----	-2070
		180	----	-2110	----	----	----	-2110
60G	1000	1	0	0	0	0	0	0
		7	----	----	340	320	310	----
		28	-1390	-1370	----	----	----	-1380
		56	-1850	-1810	----	----	----	-1830
		90	-1990	-1920	----	----	----	-1955
		180	-2040	----	----	----	----	-2040
61G	1000	1	0	0	0	0	0	0
		7	----	----	310	280	295	----
		28	-880	-880	----	----	----	-880
		56	-1220	-1220	----	----	----	-1220
		90	-1330	-1290	----	----	----	-1295
		180	-1410	-1410	----	----	----	-1410
62G	1000	1	0	0	0	0	0	0
		7	----	----	320	280	300	----
		28	-700	-680	----	----	----	-690
		56	-1000	-980	----	----	----	-990
		90	-1090	-1090	----	----	----	-1090
		180	-1150	-1200	----	----	----	-1175
63G	1000	1	0	0	0	0	0	0
		7	----	----	280	290	285	----
		28	-620	-600	----	----	----	-610
		56	-910	-880	----	----	----	-895
		90	-1000	-1000	----	----	----	-1000
		180	-1090	-1090	----	----	----	-1090

**Appendix II (j): Shrinkage and Expansion Data of Cement Paste Containing Cement
Type II (Initial Reading Was Taken after One Day of Curing)**

Mix No.	Cement content (gr)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)					
			Air-dried (Shrinkage)		Water-cured (Expansion)		Average (Expansion)	Average (Shrinkage)
64G	1000	1	0	0	0	0	0	0
		7	----	----	280	230	255	----
		28	-890	-850	----	----	----	-870
		56	-1190	-1190	----	----	----	-1190
		90	-1310	-1300	----	----	----	-1305
		180	-1400	-1410	----	----	----	-1405
65G	1000	1	0	0	0	0	0	0
		7	----	----	310	300	305	----
		28	-670	-680	----	----	----	-675
		56	-1010	-1010	----	----	----	-1010
		90	-1130	-1090	----	----	----	-1110
		180	-1230	-1170	----	----	----	-1200
66G	1000	1	0	0	0	0	0	0
		7	----	----	330	----	330	----
		28	-590	----	----	----	----	-590
		56	-920	----	----	----	----	-920
		90	-1010	----	----	----	----	-1010
		180	-1110	----	----	----	----	-1110
67G	1000	1	0	0	0	0	0	0
		7	----	----	190	230	210	----
		28	-1810	-1790	----	----	----	-1800
		56	-2160	-2150	----	----	----	-2155
		90	-2030	-2020	----	----	----	-2025
		180	-2080	-2080	----	----	----	-2080
68G	1000	1	0	0	0	0	0	0
		7	----	----	200	190	195	----
		28	-2260	-2220	----	----	----	-2240
		56	-2480	-2470	----	----	----	-2475
		90	-2320	-2320	----	----	----	-2320
		180	-2390	-2340	----	----	----	-2365
69G	1000	1	0	0	0	0	0	0
		7	----	----	200	190	195	----
		28	-2270	-2350	----	----	----	-2310
		56	-2570	-2580	----	----	----	-2575
		90	-2520	-2550	----	----	----	-2535
		180	-2580	-2570	----	----	----	-2575
70G	1000	1	0	0	0	0	0	0
		7	----	----	190	170	180	----
		28	-2550	-2520	----	----	----	-2535
		56	-2830	-2860	----	----	----	-2845
		90	-2790	-2900	----	----	----	-2845
		180	-2930	-3040	----	----	----	-2985

**Appendix II (k): Shrinkage and Expansion Data of Cement Paste Containing Cement
Type II (Initial Reading Was Taken after One Day of Curing)**

Mix No.	Cement content (gr)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)					
			Air-dried (Shrinkage)		Water-cured (Expansion)		Average (Expansion)	Average (Shrinkage)
71G	1000	1	0	0	0	0	0	0
		7	----	-----	210	170	190	----
		28	-2850	-2770	-----	-----	-----	-2810
		56	-3250	-3120	-----	-----	-----	-3185
		90	-3500	-3330	-----	-----	-----	-3415
		180	-3960	-3700	-----	-----	-----	-3830
72G	1000	1	0	0	0	0	0	0
		7	----	-----	230	220	225	----
		28	-2200	-2180	-----	-----	-----	-2190
		56	-2630	-2630	-----	-----	-----	-2630
		90	-----	-----	-----	-----	-----	-2615
		180	-2650	-2650	-----	-----	-----	-2650
73G	1000	1	0	0	0	0	0	0
		7	----	-----	200	160	180	----
		28	-2410	-2380	-----	-----	-----	-2395
		56	-2770	-2750	-----	-----	-----	-2760
		90	-2850	-2780	-----	-----	-----	-2815
		180	-2920	-2840	-----	-----	-----	-2880
74G	1000	1	0	0	0	0	0	0
		7	----	-----	160	140	150	----
		28	-2400	-2480	-----	-----	-----	-2440
		56	-2810	-2900	-----	-----	-----	-2855
		90	-2890	-2970	-----	-----	-----	-2930
		180	-2950	-3050	-----	-----	-----	-3000
75G	1000	1	0	0	0	0	0	0
		7	----	-----	170	180	175	----
		28	-2710	-2720	-----	-----	-----	-2715
		56	-3170	-3250	-----	-----	-----	-3210
		90	-3320	-3440	-----	-----	-----	-3380
		180	-3500	-3710	-----	-----	-----	-3605
76G	1000	1	0	0	0	0	0	0
		7	----	-----	310	260	285	----
		28	-2740	-2800	-----	-----	-----	-2770
		56	-3360	-3500	-----	-----	-----	-3430
		90	-3880	-4070	-----	-----	-----	-3975
		180	-4460	-4750	-----	-----	-----	-4605
77G	1000	1	0	0	0	0	0	0
		7	----	-----	270	260	265	----
		28	-1380	-1380	-----	-----	-----	-1380
		56	-1640	-1640	-----	-----	-----	-1640
		90	-1680	-1690	-----	-----	-----	-1685
		180	-1920	-1910	-----	-----	-----	-1915

**Appendix II (I): Shrinkage and Expansion Data of Cement Paste Containing Cement
Type II (Initial Reading Was Taken after One Day of Curing)**

Mix No.	Cement content (gr)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)					
			Air-dried (Shrinkage)		Water-cured (Expansion)		Average (Expansion)	Average (Shrinkage)
78G	1000	1	0	0	0	0	0	0
		7	----	----	280	320	300	----
		28	-1380	-1340	----	----	----	-1360
		56	-1680	-1630	----	----	----	-1655
		90	-1710	-1660	----	----	----	-1685
		180	-1960	-1970	----	----	----	-1965
79G	1000	1	0	0	0	0	0	0
		7	----	----	270	310	290	----
		28	-1330	-1390	----	----	----	-1360
		56	-1670	-1690	----	----	----	-1680
		90	-1710	-1720	----	----	----	-1715
		180	-1940	-1900	----	----	----	-1920
80G	1000	1	0	0	0	0	0	0
		7	----	----	150	130	140	----
		21	-1990	-2100	----	----	----	-2000
		63	-2540	-2730	----	----	----	-2635
		90	-2550	-2690	----	----	----	-2620
		180	-2920	-3160	----	----	----	-3040
81G	1000	1	0	0	0	0	0	0
		7	----	----	180	150	165	----
		21	-2190	-2250	----	----	----	-2220
		63	-2320	-2310	----	----	----	-2315
		90	----	----	----	----	----	----
		180	-2500	-2530	----	----	----	-2540

Appendix II: Mix No. 1G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 2G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 3G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Appendix II: Mix No. 4G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 5G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 6G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Appendix II: Mix No. 7G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 8G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 9G

Shrinkage and expansion of cement paste initial zero reading was taken one day after curing

Appendix II: Mix No. 10G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 11G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 12G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Appendix II: Mix No. 13G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 14G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 15G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Appendix II: Mix No. 16G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 17G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 18G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Appendix II: Mix No. 19G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 20G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 21G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Appendix II: Mix No. 22G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 23G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 24G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Appendix II: Mix No. 25G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 26G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 27G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Appendix II: Mix No. 28G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 29G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 30G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Appendix II: Mix No. 31G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 32G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 33G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Appendix II: Mix No. 34G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 35G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 36G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Appendix II: Mix No. 37G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 38G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 39G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Appendix II: Mix No. 40G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 41G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 42G

Shrinkage and expansion of cement paste initial zero reading was taken out after one day of curing

Appendix II: Mix No. 43G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 44G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 45G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Appendix II: Mix No. 46G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 47G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 48G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Appendix II: Mix No. 49G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 50G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 51G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Appendix II: Mix No. 52G

Shrinkage and expansion of cement paste initial reading was taken after one day of curing

Mix No. 53G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 54G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Appendix II: Mix No. 55G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 56G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 57G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Appendix II: Mix No. 58G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 59G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 60G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Appendix II: Mix No. 61G
 Shrinkage and expansion of cement paste initial zero
 reading was taken after one day of curing

Mix No. 62G
 Shrinkage and expansion of cement paste initial zero
 reading was taken after one day of curing

Mix No. 63G
 Shrinkage and expansion of cement paste initial zero
 reading was taken after one day of curing

Appendix II: Mix No. 64G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 65G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 66G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Appendix II: Mix No. 67G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 68G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 69G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Appendix II: Mix No. 70G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 71G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 72G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Appendix II: Mix No. 73G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 74G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 75G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Appendix II: Mix No. 76G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 77G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 78G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Appendix II: Mix No. 79G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 80G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

Mix No. 81G

Shrinkage and expansion of cement paste initial zero reading was taken after one day of curing

**Appendix III: Shrinkage and Expansion Data of Concrete Containing Cement
Type II (Initial Zero Reading at Seven Days after Curing)**

**Appendix III (a): Shrinkage and Expansion Data of Concrete Containing Cement Type II
(Initial Zero Reading at Seven Days after Curing)**

Mix No.	Cement content (lb/cyd)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)							
			Air-dried (Shrinkage)			Water-cured (Expansion)			Average (Expansion)	Average (Shrinkage)
1C	631	0	0	0	0	0	0	0	0	0
		14	-80	-70	-20	-----	-----	-----	-----	-57
		28	-110	-90	-50	-----	-----	-----	-----	-83
		56	-190	-200	-170	-----	-----	-----	-----	-187
		90	-220	-210	-190	-----	-----	-----	-----	-207
		180	-250	-250	-220	-----	-----	-----	-----	-240
2C	631	0	0	0	0	0	0	0	0	0
		7	-120	-130	-140	-----	-----	-----	-----	-130
		28	-250	-270	-280	-----	-----	-----	-----	-267
		56	-----	-----	-----	-----	-----	-----	-----	-----
		90	-340	-350	-350	-----	-----	-----	-----	-347
		180	-350	-350	-330	-----	-----	-----	-----	-343
3C	631	0	0	0	0	0	0	0	0	0
		14	-210	-240	-220	-----	-----	-----	-----	-223
		28	-----	-----	-----	-----	-----	-----	-----	-----
		56	-300	-280	-280	-----	-----	-----	-----	-287
		90	-350	-320	-360	-----	-----	-----	-----	-343
		180	-330	-320	-340	-----	-----	-----	-----	-330
4C	631	0	0	0	0	0	0	0	0	0
		7	-70	-90	-100	-----	-----	-----	-----	-87
		28	-100	-150	-170	-----	-----	-----	-----	-140
		56	-170	-240	-220	-----	-----	-----	-----	-210
		90	-230	-290	-280	-----	-----	-----	-----	-267
		180	-240	-280	-270	-----	-----	-----	-----	-263
5C	631	0	0	0	0	0	0	0	0	0
		7	-110	-160	-90	-----	-----	-----	-----	-120
		28	-310	-350	-300	-----	-----	-----	-----	-320
		56	-----	-----	-----	-----	-----	-----	-----	-----
		90	-350	-470	-360	-----	-----	-----	-----	-390
		180	-330	-450	-360	-----	-----	-----	-----	-380
6C	631	0	0	0	0	0	0	0	0	0
		7	-120	-50	-90	-----	-----	-----	-----	-87
		28	-250	-240	-240	-----	-----	-----	-----	-243
		56	-----	-----	-----	-----	-----	-----	-----	-----
		90	-300	-240	-250	-----	-----	-----	-----	-263
		180	-280	-220	-260	-----	-----	-----	-----	-253
7C	631	0	0	0	0	0	0	0	0	0
		7	-40	-50	-----	-----	-----	-----	-----	-45
		28	-170	-130	-----	-----	-----	-----	-----	-150
		56	-220	-220	-----	-----	-----	-----	-----	-220
		90	-260	-240	-----	-----	-----	-----	-----	-250
		180	-250	-240	-----	-----	-----	-----	-----	-245

**Appendix III (b): Shrinkage and Expansion Data of Concrete Containing Cement Type II
(Initial Zero Reading at Seven Days after Curing)**

Mix No.	Cement content (lb/cyd)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)							
			Air-dried (Shrinkage)			Water-cured (Expansion)			Average (Expansion)	Average (Shrinkage)
8C	631	0	0	0	0	0	0	0	0	0
		7	-80	-80	-60	-----	-----	-----	-----	-73
		28	-150	-120	-90	-----	-----	-----	-----	-120
		56	-180	-190	-190	-----	-----	-----	-----	-187
		90	-290	-200	-210	-----	-----	-----	-----	-233
		180	-200	-190	-200	-----	-----	-----	-----	-197
9C	631	0	0	0	0	0	0	0	0	0
		7	-130	-190	-180	-----	-----	-----	-----	-167
		28	-260	-320	-310	-----	-----	-----	-----	-297
		56	-370	-440	-410	-----	-----	-----	-----	-407
		90	-380	-420	-390	-----	-----	-----	-----	-397
		180	-340	-400	-400	-----	-----	-----	-----	-380
10C	631	0	0	0	0	0	0	0	0	0
		7	-90	-40	-----	-----	-----	-----	-----	-65
		28	-220	-150	-----	-----	-----	-----	-----	-185
		56	-290	-240	-----	-----	-----	-----	-----	-265
		90	-300	-250	-----	-----	-----	-----	-----	-275
		180	-280	-230	-----	-----	-----	-----	-----	-255
11C	631	0	0	0	0	0	0	0	0	0
		7	-20	-60	-10	-----	-----	-----	-----	-30
		28	-150	-230	-100	-----	-----	-----	-----	-160
		56	-230	-310	-190	-----	-----	-----	-----	-243
		90	-220	-410	-230	-----	-----	-----	-----	-287
		180	-210	-300	-210	-----	-----	-----	-----	-240
12C	631	0	0	0	0	0	0	0	0	0
		7	-50	-20	-30	-----	-----	-----	-----	-33
		28	-180	-150	-160	-----	-----	-----	-----	-163
		56	-260	-250	-260	-----	-----	-----	-----	-257
		90	-270	-270	-260	-----	-----	-----	-----	-267
		180	-240	-250	-240	-----	-----	-----	-----	-243
13C	631	0	0	0	0	0	0	0	0	0
		7	-80	-110	-90	-----	-----	-----	-----	-93
		28	-180	-200	-180	-----	-----	-----	-----	-187
		56	-----	-----	-----	-----	-----	-----	-----	-----
		90	-280	-270	-250	-----	-----	-----	-----	-267
		180	-250	-230	-220	-----	-----	-----	-----	-233
14C	631	0	0	0	0	0	0	0	0	0
		7	-50	-60	-50	-----	-----	-----	-----	-57
		28	-140	-130	-150	-----	-----	-----	-----	-140
		56	-----	-----	-----	-----	-----	-----	-----	-----
		90	-210	-180	-200	-----	-----	-----	-----	-197
		180	-170	-160	-180	-----	-----	-----	-----	-170

**Appendix III (c): Shrinkage and Expansion Data of Concrete Containing Cement Type II
(Initial Zero Reading at Seven Days after Curing)**

Mix No.	Cement content (lb/cyd)	Age (days)	Shrinkage (x10 ⁻⁶ in./in.)							
			Air-dried (Shrinkage)			Water-cured (Expansion)		Average (Expansion)	Average (Shrinkage)	
15C	631	0	0	0	0	0	0	0	0	
		7	-40	-30	30				-13	
		28	-100	-80	-60				-80	
		56	-150	-150	-150				-150	
		90	-170	-140	-140				-150	
		180	-140	-160	-120				-140	
16C	631	0	0	0	0	0	0	0	0	
		7	-30	-40	-10				-27	
		28	-90	-90	-90				-90	
		56	-140	-140	-140				-140	
		90	-170	-140	-150				-153	
		180	-170	-160	-160				-163	
17C	631	0	0	0	0	0	0	0	0	
		7	-140	-220	-270				-210	
		21	-280	-290	-380				-317	
		56								
		90	-400	-400	-510				-437	
		180	-390	-390	-490				-423	
18C	631	0	0	0	0	0	0	0	0	
		7	-90	-90	-100				-93	
		28	-250	-260	-250				-253	
		56	-310	-340	-310				-320	
		90	-330	-360	-360				-350	
		180	-340	-370	-350				-350	
19C	631	0	0	0	0	0	0	0	0	
		7	-130	-100	-80				-103	
		21	-220	-210	-210				-213	
		56								
		90	-320	-300	-290				-303	
		180	-250	-220	-250				-240	
20C	631	0	0	0	0	0	0	0	0	
		7	-60	-40	-30				-43	
		28	-160	-130	-110				-133	
		56	-250	-200	-170				-207	
		90	-220	-210	-180				-203	
		180	-260	-220	-200				-227	
21C	631	0	0	0	0	0	0	0	0	
		7	-30	-20	-40				-30	
		28	-110	-110	-110				-110	
		56	-200	-170	-160				-177	
		90	-180	-160	-170				-170	
		180	-190	-220	-180				-197	

**Appendix III (d): Shrinkage and Expansion Data of Concrete Containing Cement Type II
(Initial Zero Reading at Seven Days after Curing)**

Mix No.	Cement content (lb/cyd)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)							
			Air-dried (Shrinkage)			Water-cured (Expansion)		Average (Expansion)		Average (Shrinkage)
22C	631	0	0	0	0	0	0	0	0	0
		7	-60	-50	-50					-53
		28	-140	-100	-110					-117
		56	-170	-150	-150					-157
		90	-230	-160	-160					-183
		180	-230	-160	-170					-187
23C	631	0	0	0	0	0	0	0	0	0
		7	-20	-210	-200					-203
		28	-350	-370	-360					-360
		56	-430	-470	-380					-427
		90	-390	-380	-380					-383
		180	-420	-410	-420					-417
24C	631	0	0	0	0	0	0	0	0	0
		7	-90	-90	-100					-93
		21	-140	-140	-140					-140
		56								
		90	-230	-200	-220					-217
		180	-230	-240	-240					-237
25C	631	0	0	0	0	0	0	0	0	0
		7	-180	-170	-190					-180
		21	-350	-330	-350					-343
		56								
		90	-410	-430	-460					-433
		180	-400	-370	-410					-393
26C	631	Mix was so dry								
27C	631	0	0	0	0	0	0	0	0	0
		7	-140	-130	-140					-137
		28	-190	-160	-175					-175
		56	-240	-230	-250					-240
		90	-250	-210	-250					-237
		180	-290	-260	-290					-280
28C	631	0	0	0	0	0	0	0	0	0
		7	-40	-40	-70					-50
		28	-80	-70	-100					-83
		56								
		90	-190	-200	-250					-213
		180	-190	-180	-200					-190
29C	631	0	0	0	0	0	0	0	0	0
		7	-30	-70	-30					-43
		28	-80	-130	-120					-110
		56								
		90	-170	-220	-220					-203
		180	-150	-210	-220					-193

**Appendix III (e): Shrinkage and Expansion Data of Concrete Containing Cement Type II
(Initial Zero Reading at Seven Days after Curing)**

Mix No.	Cement content (lb/cyd)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)							
			Air-dried (Shrinkage)			Water-cured (Expansion)			Average (Expansion)	Average (Shrinkage)
30C	631	0	0	0	0	0	0	0	0	0
		7	-30	-50	-40	----	----	----	----	-40
		28	-110	-120	-150	----	----	----	----	-127
		56	-170	-190	-200	----	----	----	----	-187
		90	-180	-210	-220	----	----	----	----	-203
		180	-220	-220	-210	----	----	----	----	-217
31C	675	0	0	0	0	0	0	0	0	0
		10	-190	-160	-180	----	----	----	----	-177
		21	-260	-240	-280	----	----	----	----	-260
		56	-340	-320	-370	----	----	----	----	-343
		90	-400	-360	-380	----	----	----	----	-380
		180	-360	-330	-370	----	----	----	----	-353
32C	675	0	0	0	0	0	0	0	0	0
		10	-250	-240	-190	----	----	----	----	-227
		21	-280	-370	-340	----	----	----	----	-330
		56	-420	-440	-420	----	----	----	----	-427
		90	-460	-470	-470	----	----	----	----	-467
		180	-440	-450	-450	----	----	----	----	-447
33C	628	0	0	0	0	0	0	0	0	0
		10	-180	-170	-220	----	----	----	----	-190
		21	-280	-270	-280	----	----	----	----	-277
		56	-360	-320	-360	----	----	----	----	-347
		90	-390	-350	-400	----	----	----	----	-380
		180	-350	-350	-370	----	----	----	----	-357
34C	702	0	0	0	0	0	0	0	0	0
		7	-130	-170	-150	----	----	----	----	-150
		28	-240	-260	-230	----	----	----	----	-243
		56	-360	-360	-370	----	----	----	----	-363
		90	-370	-390	-380	----	----	----	----	-380
		180	-390	-400	-390	----	----	----	----	-393

Appendix III: Mix No. 1C
 Shrinkage of concrete initial zero reading at seven days of curing

Mix No. 2C
 Shrinkage of concrete initial zero reading at seven days after curing

Mix No. 3C
 Shrinkage of concrete initial zero reading at seven days after curing

Appendix III: Mix No. 4C
Shrinkage of concrete initial zero reading at seven days after curing

Mix No. 5C
Shrinkage of concrete initial zero reading at seven days after curing

Mix No. 6C
Shrinkage of concrete initial zero reading at seven days after curing

Appendix III: Mix No. 7C

Shrinkage of concrete initial zero reading at seven days of curing

Mix No. 8C

Shrinkage of concrete initial zero reading at seven days of curing

Mix No. 9C

Shrinkage of concrete initial zero reading at seven days of curing

Appendix III: Mix No. 10C

Shrinkage of concrete initial zero reading at seven days after curing

Mix No. 11C

Shrinkage of concrete initial zero reading at seven days after curing

Mix No. 12C

Shrinkage of concrete initial zero reading at seven days after curing

Appendix III: Mix No. 13C

Shrinkage of concrete initial zero reading at seven days after curing

Mix No. 14C

Shrinkage of concrete initial zero reading at seven days after curing

Mix No. 15C

Shrinkage of concrete initial zero reading at seven days after curing

Appendix III: Mix No. 16C

Shrinkage of concrete initial zero reading at seven days
after curing

Mix No. 17C

Shrinkage of concrete initial zero reading at seven days
after curing

Mix No. 18C

Shrinkage of concrete initial zero reading at seven days
after curing

Appendix III: Mix No. 19C

Shrinkage of concrete initial zero reading at seven days
after curing

Mix No. 20C

Shrinkage of concrete initial zero reading at seven days
after curing

Mix No. 21C

Shrinkage of concrete initial zero reading at seven days
after curing

Appendix III: Mix No. 22C

Shrinkage of concrete initial zero reading at seven days after curing

Mix No. 23C

Shrinkage of concrete initial zero reading at seven days after curing

Mix No. 24C

Shrinkage of concrete initial zero reading at seven days after curing

Appendix III: Mix No. 25C

Shrinkage of concrete initial zero reading at seven days after curing

Mix No. 27C

Shrinkage of concrete initial zero reading at seven days after curing

Mix No. 28C

Shrinkage of concrete initial zero reading at seven days after curing

Appendix III: Mix No. 29C
 Shrinkage of concrete initial zero reading at seven days
 after curing

Mix No. 30C
 Shrinkage of concrete initial zero reading at seven days
 after curing

Mix No. 31C
 Shrinkage of concrete initial zero reading at seven days
 after curing

Appendix III: Mix No. 32C

Shrinkage of concrete initial zero reading at seven days
after curing

Mix No. 33C

Shrinkage of concrete initial zero reading at seven days
after curing

Mix No. 34C

Shrinkage of concrete initial zero reading at seven days
after curing

**Appendix IV: Shrinkage and Expansion Data of Concrete Containing Cement
Type II (Initial Reading Was Taken after One Day of Curing)**

**Appendix IV (a): Shrinkage and Expansion Data of Concrete Containing Cement Type II
(Initial Reading Was Taken after One Day of Curing)**

Mix No.	Cement content (lb/cyd)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)							
			Air-dried (Shrinkage)			Water-cured (Expansion)		Average (Expansion)		Average (Shrinkage)
1C	631	1	0	0	0	0	0	0	0	0
		7	----	----	----	-30	-30	20	-13	----
		28	-140	-120	-80	----	----	----	----	-113
		56	-220	-220	-180	----	----	----	----	-207
		90	-250	-250	-210	----	----	----	----	-237
		180	-280	-280	-250	----	----	----	----	-270
2C	631	1	0	0	0	0	0	0	0	0
		7	----	----	----	-20	20	0	0	----
		21	-180	-190	-190	----	----	----	----	-187
		56	-220	-230	-230	----	----	----	----	-227
		90	-370	-360	-370	----	----	----	----	-367
		180	-370	-340	-340	----	----	----	----	-350
3C	631	1	0	0	0	0	0	0	0	0
		7	----	----	----	70	40	60	57	----
		21	-140	-200	-160	----	----	----	----	-167
		56	-230	-240	-220	----	----	----	----	-230
		90	-260	-270	-280	----	----	----	----	-270
		180	-250	-270	-260	----	----	----	----	-260
4C	631	1	0	0	0	0	0	0	0	0
		7	----	----	----	50	30	80	53	----
		21	-30	-110	-70	----	----	----	----	-70
		56	----	----	----	----	----	----	----	----
		90	-180	-260	-240	----	----	----	----	-227
		180	-190	-250	-190	----	----	----	----	-210
5C	631	1	0	0	0	0	0	0	0	0
		7	----	----	----	-10	80	-20	17	----
		28	-280	-240	-230	----	----	----	----	-250
		56	----	----	----	----	----	----	----	----
		90	-350	-370	-390	----	----	----	----	-370
		180	-350	-370	-380	----	----	----	----	-367
6C	631	1	0	0	0	0	0	0	0	0
		7	----	----	----	60	0	80	47	----
		28	-150	-130	-80	----	----	----	----	-120
		56	----	----	----	----	----	----	----	----
		90	-280	-250	-160	----	----	----	----	-230
		180	-220	-230	-170	----	----	----	----	207
7C	631	1	0	0	0	0	0	0	0	0
		7	----	----	----	110	120	----	115	----
		28	----	----	----	----	----	----	----	----
		56	-100	-90	----	----	----	----	----	-95
		90	-130	-100	----	----	----	----	----	-115
		180	-160	-130	----	----	----	----	----	-145

**Appendix IV (b): Shrinkage and Expansion Data of Concrete Containing Cement Type II
(Initial Reading Was Taken after One Day of Curing)**

Mix No.	Cement content (lb/cyd)	Age (days)	Shrinkage (x10 ⁻⁶ in./in.)							
			Air-dried (Shrinkage)			Water-cured (Expansion)		Average (Expansion)	Average (Shrinkage)	
8C	631	1	0	0	0	0	0	0	0	0
		7				80	30	60	57	
		35	-70	-90	-30					-63
		56	-90	-160	-130					-123
		90	-140	-170	-130					-147
		180	-130	-170	-130					-143
9C	631	1	0	0	0	0	0	0	0	0
		7				10	10	30	17	
		21	-200	-230	-190					-207
		56	-320	-380	-340					-347
		90	-360	-410	-380					-383
		180	-340	-400	-370					-370
10C	631	1	0	0	0	0	0	0	0	0
		7				60	20		40	
		21	-90	-80						-85
		56	-190	-170						-180
		90	-230	-220						-225
		180	-230	-200						-215
11C	631	1	0	0	0	0	0	0	0	0
		7				30	30	30	30	
		28	-110	-200	-50					-120
		56	-150	-250	-110					-170
		90	-190	-380	-200					-257
		180	-180	-280	-190					217
12C	631	1	0	0	0	0	0	0	0	0
		7				30	40	30	33	
		28	-140	-60	-90					-97
		56	-200	-180	-190					-190
		90	-240	-230	-230					-233
		180	-210	-220	-220					-217
13C	631	1	0	0	0	0	0	0	0	0
		7				-20	20	30	10	
		28	-150	-120	-120					-130
		56	-240	-190	-150					-193
		90								
		180	-270	-200	-180					-217
14C	631	1	0	0	0	0	0	0	0	0
		7				20	20	30	23	
		28	-80	-90	-80					-83
		56								
		90								
		180	-150	-140	-160					-150

**Appendix IV (c): Shrinkage and Expansion Data of Concrete Containing Cement Type II
(Initial Reading Was Taken after One Day of Curing)**

Mix No.	Cement content (lb/cyd)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)							
			Air-dried (Shrinkage)			Water-cured (Expansion)			Average (Expansion)	Average (Shrinkage)
15C	631	1	0	0	0	0	0	0	0	0
		7	----	----	----	-30	-50	-310	-130	----
		28	-120	-120	-330	----	----	----	----	-190
		56	----	----	----	----	----	----	----	----
		90	----	----	----	----	----	----	----	----
		180	-160	-190	-430	----	----	----	----	-260
16C	631	1	0	0	0	0	0	0	0	0
		7	----	----	----	-90	-20	0	-37	----
		28	-170	-80	-60	----	----	----	----	-155
		56	----	----	----	----	----	----	----	----
		90	----	----	----	----	----	----	----	----
		180	-240	-170	-140	----	----	----	----	-183
17C	631	1	0	0	0	0	0	0	0	0
		7	----	----	----	10	40	100	50	----
		28	-270	-250	-280	----	----	----	----	-267
		56	-340	-320	-350	----	----	----	----	-337
		90	----	----	----	----	----	----	----	----
		180	-380	-340	-390	----	----	----	----	-370
18C	631	1	0	0	0	0	0	0	0	0
		7	----	----	----	120	70	70	87	----
		28	-110	-170	-150	----	----	----	----	-143
		56	----	----	----	----	----	----	----	----
		90	-200	-310	-280	----	----	----	----	-263
		180	-240	-320	-300	----	----	----	----	-287
19C	631	1	0	0	0	0	0	0	0	0
		7	----	----	----	70	50	20	47	----
		28	-150	-160	-190	----	----	----	----	-167
		56	-190	-200	-210	----	----	----	----	-200
		90	----	----	----	----	----	----	----	----
		180	-250	-220	-250	----	----	----	----	-240
20C	631	1	0	0	0	0	0	0	0	0
		7	----	----	----	60	40	50	60	----
		28	-50	-100	-50	----	----	----	----	-67
		56	----	----	----	----	----	----	----	----
		90	-170	-180	-140	----	----	----	----	-163
		180	-170	-190	-140	----	----	----	----	-167
21C	631	1	0	0	0	0	0	0	0	0
		7	----	----	----	20	20	20	20	----
		28	-80	-80	-80	----	----	----	----	-80
		56	----	----	----	----	----	----	----	----
		90	-170	-160	-170	----	----	----	----	-167
		180	-170	-200	-170	----	----	----	----	-180

**Appendix IV (d): Shrinkage and Expansion Data of Concrete Containing Cement Type II
(Initial Reading Was Taken after One Day of Curing)**

Mix No.	Cement content (lb/cyd)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)							
			Air-dried (Shrinkage)			Water-cured (Expansion)			Average (Expansion)	Average (Shrinkage)
22C	631	1	0	0	0	0	0	0	0	0
		7	----	----	----	20	50	-30	13	----
		28	-90	-30	-120	----	----	----	----	-80
		56	-160	-130	-200	----	----	----	----	-163
		90	-220	-130	-200	----	----	----	----	-183
		180	-230	-110	-230	----	----	----	----	-190
23C	631	1	0	0	0	0	0	0	0	0
		7	----	----	----	10	0	20	10	----
		28	-280	-210	-270	----	----	----	----	-287
		56	-400	-420	-350	----	----	----	----	-390
		90	-400	-400	-360	----	----	----	----	-387
		180	-390	-400	-380	----	----	----	----	-390
24C	631	1	0	0	0	0	0	0	0	0
		7	----	----	----	40	10	20	23	----
		28	-100	-130	-120	----	----	----	----	-117
		56	-220	-260	-180	----	----	----	----	-220
		90	-190	-190	-200	----	----	----	----	-193
		180	-190	-230	-230	----	----	----	----	-217
25C	631	1	0	0	0	0	0	0	0	0
		7	----	----	----	40	30	40	37	----
		28	-310	-300	-310	----	----	----	----	-307
		56	-360	-360	-360	----	----	----	----	-360
		90	-370	-400	-420	----	----	----	----	-397
		180	-360	-340	-370	----	----	----	----	-357
26C	631	Mix was so dry								
27C	631	1	0	0	0	0	0	0	0	0
		7	----	----	----	50	30	50	43	----
		28	-130	-120	-100	----	----	----	----	-117
		56	----	----	----	----	----	----	----	----
		90	-190	-190	-200	----	----	----	----	-193
		180	-240	-230	-240	----	----	----	----	-237
28C	631	1	0	0	0	0	0	0	0	0
		7	----	----	----	-60	-50	-10	-40	----
		28	-160	-140	-120	----	----	----	----	-140
		56	-220	-190	-190	----	----	----	----	-200
		90	-250	-250	-260	----	----	----	----	-253
		180	-250	-240	-220	----	----	----	----	-237
29C	631	1	0	0	0	0	0	0	0	0
		7	----	----	----	140	70	70	93	----
		28	40	-70	-80	----	----	----	----	-37
		56	50	-70	-100	----	----	----	----	-40
		90	-30	-150	-150	----	----	----	----	-110
		180	-10	-140	-140	----	----	----	----	-97

**Appendix IV (e): Shrinkage and Expansion Data of Concrete Containing Cement Type II
(Initial Reading Was Taken after One Day of Curing)**

Mix No.	Cement content (lb/cyd)	Age (days)	Shrinkage ($\times 10^{-6}$ in./in.)							
			Air-dried (Shrinkage)			Water-cured (Expansion)			Average (Expansion)	Average (Shrinkage)
30C	631	1	0	0	0	0	0	0	0	0
		7	----	----	----	70	80	160	103	----
		28	-100	-200	600	----	----	----	----	100
		56	-90	-100	-40	----	----	----	----	-77
		90	-110	-130	-60	----	----	----	----	-100
		180	-170	-160	-60	----	----	----	----	-130
31C	675	1	0	0	0	0	0	0	0	0
		7	----	----	----	80	10	10	33	----
		28	-180	-230	-270	----	----	----	----	-227
		56	-280	-320	-350	----	----	----	----	-317
		90	-270	-320	-360	----	----	----	----	-317
		180	-290	-340	-380	----	----	----	----	-337
32C	675	1	0	0	0	0	0	0	0	0
		7	----	----	----	80	90	80	83	----
		28	-200	-280	-260	----	----	----	----	-247
		56	-350	-350	-340	----	----	----	----	-347
		90	-360	-360	-350	----	----	----	----	-357
		180	-370	-380	-390	----	----	----	----	-380
33C	628	1	0	0	0	0	0	0	0	0
		7	----	----	----	20	20	10	17	----
		28	-260	-250	-270	----	----	----	----	-260
		56	-330	-310	-360	----	----	----	----	-333
		90	-350	-310	-360	----	----	----	----	-340
		180	-340	-340	-390	----	----	----	----	-357
34C	702	1	0	0	0	0	0	0	0	0
		7	----	----	----	40	10	40	30	----
		28	-200	-250	-190	----	----	----	----	-213
		56	-270	-300	-270	----	----	----	----	-280
		90	-330	-370	-330	----	----	----	----	-343
		180	-360	-400	-340	----	----	----	----	-367

Appendix IV: Mix No. 1C
 Shrinkage and expansion of concrete initial zero reading
 was taken after one day of curing

Mix No. 2C
 Shrinkage and expansion initial zero reading was taken
 after one day of curing

Mix No. 3C
 Shrinkage and expansion of concrete initial zero reading
 was taken after one day of curing

Appendix IV: Mix No. 4C

Shrinkage and expansion of concrete initial zero reading
was taken after one day of curing

Mix No. 5C

Shrinkage and expansion of concrete initial zero reading
was taken after one day of curing

Mix No. 6C

Shrinkage and expansion of concrete initial zero reading
was taken after one day of curing

Appendix IV: Mix No. 7C

Shrinkage and expansion of concrete initial zero reading
was taken after one day of curing

Mix No. 8C

Shrinkage and expansion of concrete initial zero reading
was taken after one day of curing

Mix No. 9C

Shrinkage and expansion of concrete initial zero reading
was taken after one day of curing

Appendix IV: Mix No. 10C

Shrinkage and expansion of concrete initial zero reading
was taken after one day of curing

Mix No. 11C

Shrinkage and expansion of concrete initial zero reading
was taken after one day of curing

Mix No. 12C

Shrinkage and expansion of concrete initial zero reading
was taken after one day of curing

Appendix IV: Mix No. 13C
Shrinkage and expansion of concrete initial zero reading
was taken after one day of curing

Mix No. 14C
Shrinkage and expansion of concrete initial zero reading
was taken after one day of curing

Mix No. 15C
Shrinkage and expansion of concrete initial zero reading
was taken after one day of curing

Appendix IV: Mix No. 16C

Shrinkage and expansion of concrete initial zero reading
was taken after one day of curing

Mix No. 17C

Shrinkage and expansion of concrete initial zero reading
was taken after one day of curing

Mix No. 18C

Shrinkage and expansion of concrete initial zero reading
was taken after one day of curing

Appendix IV: Mix No. 19C
Shrinkage and expansion of concrete initial zero reading
was taken after one day of curing

Mix No. 20C
Shrinkage and expansion of concrete initial zero reading
was taken after one day of curing

Mix No. 21C
Shrinkage and expansion of concrete initial zero reading
was taken after one day of curing

Appendix IV: Mix No. 22C

Shrinkage and expansion of concrete initial zero reading
was taken after one day curing

Mix No. 23C

Shrinkage and expansion of concrete initial zero reading
was taken after one day of curing

Mix No. 24C

Shrinkage and expansion of concrete initial zero reading
was taken after one day of curing

Appendix IV: Mix No. 25C

Shrinkage and expansion of concrete initial reading was taken after one day of curing

Mix No. 27C

Shrinkage and expansion of concrete initial zero reading was taken after one day of curing

Mix No. 28C

Shrinkage and expansion of concrete initial zero reading was taken after one day of curing

Appendix IV: Mix No. 29C

Shrinkage and expansion of concrete initial zero reading
was taken after one day of curing

Mix No. 30C

Shrinkage and expansion of concrete initial zero reading
was taken after one day of curing

Mix No. 31C

Shrinkage and expansion of concrete initial zero reading
was taken after one day of curing

Appendix IV: Mix No. 32C

Shrinkage and expansion of concrete initial zero reading
was taken after one day of curing

Mix No. 33C

Shrinkage and expansion of concrete initial zero reading
was taken after one day of curing

Mix No. 34C

Shrinkage and expansion of concrete initial zero reading
was taken after one day of curing

Appendix V: Compressive Strength Data of Concrete Mixes

Appendix V (a): Compressive Strength Data of Concrete Mixes

Mix No.	w/cm	Cement Content (lb/cyd)	Age (days)	Cylinder Size (in.)	Compressive Strength (psi)		
					Spec.1	Spec.2	Average
1C	0.33	631	36	4 x 8	10565	10145	10355
			64		10838	11886	11362
			165		15034	12973	14004
2C	0.33	631	34	4 x 8	10550	10343	10518
			57		12505	12426	12466
			106		12797	13173	12980
			182		15011	14406	14709
3C	0.33	631	28	4 x 8	10530	10721	10625
			114		14456	13223	13840
4C	0.33	631	33	4 x 8	11120	10175	10648
			57		11583	11807	11695
			104		12256	12605	12419
			180		13701	13227	13464
5C	0.33	631	35	4 x 8	11259	10634	10947
			57		12204	11975	12088
			104		13138	12682	12903
			180		14816	15855	15356
6C	0.33	631	37	4 x 8	11716	11315	11515
			57		12380	11667	12023
			104		12971	13283	13102
			180		14113	15406	14759
7C	0.33	631	28	4 x 8	10560	10122	10341
			56		11059	11834	11445
			102		12988	12232	12610
			181		13893	14572	14232
8C	0.33	631	35	4 x 8	8645	8642	85554
			56		9224	9280	9252
			102		10194	10101	10139
			180		11533	11341	11437
9C	0.33	631	32	4 x 8	10470	10644	10557
			60		11117	12289	11703
			90		12504	12269	12383
			180		13139	13107	13123
10C	0.33	631	32	4 x 8	10130	9645	9888
			60		10528	11951	11236
			90		11280	11968	11624
			180		12879	13125	13002
11C	0.33	631	28	4 x 8	8689	8234	8462
			57		10247	9773	10006
			118		11542	12208	11875
			180		11361	11869	11615

Appendix V (b): Compressive Strength Data of Concrete Mixes

Mix No.	w/cm	Cement Content (lb/cyd)	Age (days)	Cylinder Size (in.)	Compressive Strength (psi)		
					Spec.1	Spec.2	Average
12C	0.33	631	28	4 x 8	9753	9979	9866
			57		12325	11934	12129
			118		15445	14812	15128
			180		14163	13744	13953
13C	0.33	631	31	4 x 8	7951	7485	7718
			56		9138	9335	9226
			137		11424	11318	11371
			180		12295	11381	11838
14C	0.33	631	31	4 x 8	8172	8353	8238
			56		9617	10722	10169
			137		12271	12187	12229
			180		13250	13177	13214
15C	0.33	631	30	4 x 8	7525	7847	7686
			57		8776	9664	9220
			136		11199	11714	11457
			180		11296	11894	11595
16C	0.33	631	32	4 x 8	7076	7282	7179
			57		9174	9384	9279
			136		11149	11080	11112
			180		12228	11023	11625
17C	0.33	631	28	4 x 8	9210	9584	9397
			58		11534	12636	12071
			139		13600	12908	13254
			180		14265	14139	14202
18C	0.33	631	28	4 x 8	7675	7526	7601
			64		10404	9741	10073
			127		11016	11612	11314
			180		12490	12732	12611
19C	0.33	631	38	4 x 8	8998	9818	9408
			58		11278	10576	10927
			139		12675	12303	12489
			180		13377	12720	13048
20C	0.33	631	----	4 x 8	----	----	----
			64		10210	10573	10283
			127		13088	11804	12446
			180		13338	12625	12981
21C	0.33	631	28	4 x 8	9599	9163	9381
			67		12150	12316	12230
			127		13046	13868	13457
			180		13538	13374	13456

Appendix V (c): Compressive Strength Data of Concrete Mixes

Mix No.	w/cm	Cement Content (lb/cyd)	Age (days)	Cylinder Size (in.)	Compressive Strength (psi)		
					Spec. 1	Spec. 2	Average
22C	0.33	631	32	4 x 8	8267	5325	8296
			70		10420	10377	10397
			125		11134	11971	11553
			180		12846	13162	13004
23C	0.33	631	29	4 x 8	11488	11382	11435
			---		---	---	---
			116		15239	15689	15464
			180		14946	15516	15231
24C	0.33	631	30	4 x 8	11476	11559	11317
			---		---	---	---
			110		13822	13825	13823
			180		14539	15363	14951
25C	0.33	631	30	4 x 8	9647	10560	10119
			---		---	---	---
			112		13042	12505	12773
			180		13862	14651	14256
27C	0.33	631	---	4 x 8	---	---	---
			---		---	---	---
			96		13982	13632	13807
			180		14911	14281	14956
28C	0.33	631	31	4 x 8	10419	10029	10224
			---		---	---	---
			85		11824	12884	12354
			180		15146	14644	14895
29C	0.33	631	30	4 x 8	10262	9654	9958
			---		---	---	---
			---		---	---	---
			180		15447	13215	14331
30C	0.33	631	28	4 x 8	9225	9738	9482
			---		---	---	---
			116		13962	13420	13691
			180		14320	13328	13824
31C	0.34	675	56	4 x 8	11590	12546	12068
			180		14258	14675	14466
			28	6 x 12	9981	9911	9927
			180		11340	---	11340
32C	0.34	675	59	4 x 8	11208	11706	11457
			180		12569	12108	12339
			28	6 x 12	9469	9118	9294
			180		10388	---	10388

Appendix V (d): Compressive Strength Data of Concrete Mixes

Mix No.	w/cm	Cement Content (lb/cyd)	Age (days)	Cylinder Size (in.)	Compressive Strength (psi)		
					Spec.1	Spec.2	Average
33C	0.34	628	57	4 x 8	9524	12681	11103
			180		14577	12858	13717
			28	6 x 12	10678	10542	10609
			180		11221	----	11221
34C	0.34	702	95	4 x 8	11947	12688	12317
			180		12425	14988	13712
			29	6 x 12	9672	10108	9890
			180		11170	----	11170

Appendix VI: Modulus of Elasticity of Concrete Mixes

Appendix VI (a): Modulus of Elasticity of Concrete Mixes

Mix No.	w/cm	Cement Content (lb/cyd)	Age (days)	Cylinder Size (in.)	Modulus of Elasticity (x10 ⁶ psi)		
					Spec.1	Spec.2	Average
1C	0.33	631	36	4 x 8	6.00	5.80	5.90
			64		6.04	5.86	5.95
			165		6.90	5.30	6.10
			180		-----	-----	-----
2C	0.33	631	34	4 x 8	5.40	5.72	5.56
			57		5.30	5.40	5.35
			106		6.00	5.40	5.70
			182		6.70	6.50	6.60
3C	0.33	631	28	4 x 8	5.36	5.30	5.33
			114		6.70	6.20	6.45
4C	0.33	631	33	4 x 8	5.17	5.17	5.17
			57		5.40	5.60	5.50
			104		5.70	5.35	5.50
			180		6.20	6.40	6.30
5C	0.33	631	35	4 x 8	6.06	6.53	6.30
			57		5.30	5.60	5.45
			104		5.66	5.70	5.68
			180		6.35	6.75	6.55
6C	0.33	631	37	4 x 8	5.83	5.50	5.60
			57		-----	5.50	5.50
			104		6.17	6.15	6.16
			180		6.20	6.30	6.25
7C	0.33	631	28	4 x 8	5.36	5.17	5.26
			56		5.90	5.80	5.85
			102		6.30	6.00	6.15
			181		5.80	6.20	6.00
8C	0.33	631	35	4 x 8	5.00	5.43	5.21
			56		5.30	5.50	5.40
			102		6.10	5.90	6.00
			180		6.10	6.20	6.15
9C	0.33	631	32	4 x 8	5.42	5.45	5.43
			60		5.70	5.50	5.60
			90		5.86	5.85	5.85
			180		6.20	6.13	6.16
10C	0.33	631	32	4 x 8	5.94	4.94	5.42
			60		5.56	5.70	5.63
			90		5.40	5.60	5.50
			180		6.50	6.70	6.60
11C	0.33	631	28	4 x 8	5.30	5.11	5.20
			57		5.14	5.80	5.51
			118		6.40	6.00	6.20
			180		6.10	6.24	6.17

Appendix VI (b): Modulus of Elasticity of Concrete Mixes

Mix No.	w/cm	Cement Content (lb/cyd)	Age (days)	Cylinder Size (in.)	Modulus of Elasticity ($\times 10^9$ psi)		
					Spec.1	Spec.2	Average
12C	0.33	631	28	4 x 8	5.50	5.19	5.34
			57		6.03	5.70	5.87
			118		6.30	6.60	6.45
			180		6.70	6.70	6.70
13C	0.33	631	31	4 x 8	4.90	4.83	4.86
			56		5.24	5.15	5.20
			137		5.80	6.25	6.00
			180		5.80	6.20	6.00
14C	0.33	631	31	4 x 8	5.00	4.82	4.90
			56		5.70	5.80	5.75
			137		6.65	6.16	6.40
			180		6.12	6.20	6.16
15C	0.33	631	30	4 x 8	4.80	4.60	4.70
			57		5.40	5.00	5.20
			136		6.12	6.10	6.11
			180		6.36	6.80	6.60
16C	0.33	631	32	4 x 8	4.80	5.20	5.00
			57		4.86	5.60	5.24
			136		5.60	5.56	5.58
			180		5.90	6.00	5.95
17C	0.33	631	28	4 x 8	4.83	5.51	5.17
			58		5.50	5.76	5.60
			139		6.06	5.90	5.98
			180		6.06	6.06	6.00
18C	0.33	631	28	4 x 8	4.30	4.50	4.40
			64		4.90	5.07	5.40
			127		5.80	5.70	5.75
			180		5.90	6.25	6.10
19C	0.33	631	38	4 x 8	4.90	5.30	5.10
			58		5.90	5.75	5.85
			139		6.20	6.12	6.16
			180		6.35	5.90	6.10
20C	0.33	631	---	4 x 8	---	---	---
			64		5.30	5.10	5.20
			127		6.24	6.10	6.17
			180		6.40	6.60	6.50
21C	0.33	631	28	4 x 8	4.63	4.80	4.72
			67		5.60	5.75	5.67
			127		6.80	5.90	6.35
			180		6.50	5.80	6.15

Appendix VI (c): Modulus of Elasticity of Concrete Mixes

Mix No.	w/cm	Cement Content (lb/cyd)	Age (days)	Cylinder Size (in.)	Modulus of Elasticity (x10 ⁶ psi)		
					Spec.1	Spec.2	Average
22C	0.33	631	32	4 x 8	4.70	4.37	4.57
			70		5.36	5.40	5.38
			125		5.90	6.50	6.20
			180		5.80	5.90	5.85
23C	0.33	631	29	4 x 8	5.47	4.27	5.37
			---		---	---	---
			116		6.03	6.20	6.11
			180		6.90	6.20	6.55
24C	0.33	631	30	4 x 8	5.00	5.60	5.30
			---		---	---	---
			110		6.20	6.40	6.30
			180		6.36	6.60	6.48
25C	0.33	631	30	4 x 8	5.10	4.90	5.00
			---		---	---	---
			112		5.70	6.03	5.86
			180		---	6.30	6.30
27C	0.33	631	---	4 x 8	---	---	---
			---		---	---	---
			96		6.15	6.56	6.35
			180		5.70	5.70	5.70
28C	0.33	631	31	4 x 8	5.40	5.00	5.20
			---		---	---	---
			85		5.98	5.97	5.98
			180		5.90	7.30	6.60
29C	0.33	631	30	4 x 8	5.24	5.50	5.37
			---		---	---	---
			---		---	---	---
			180		6.10	---	6.10
30C	0.33	631	28	4 x 8	4.74	5.30	5.02
			---		---	---	---
			116		5.90	5.90	5.90
			180		6.10	5.25	5.70
31C	0.34	675	56	4 x 8	6.14	5.94	6.04
			180	4 x 8	6.10	6.80	6.40
			28	6 x 12	5.80	6.10	5.95
			180		---	---	---
32C	0.34	675	59	4 x 8	5.70	5.50	5.60
			180	4 x 8	5.50	7.00	6.25
			28	6 x 12	5.60	5.30	5.45
			180		---	---	---

Appendix VI (d): Modulus of Elasticity of Concrete Mixes

Mix No.	w/cm	Cement Content (lb/cyd)	Age (days)	Cylinder Size (in.)	Modulus of Elasticity ($\times 10^9$ psi)		
					Spec.1	Spec.2	Average
33C	0.34	628	57	4 x 8	5.35	5.80	5.60
			180		6.30	5.90	6.10
			28	6 x 12	6.10	5.50	5.80
			180		-----	-----	-----
34C	0.34	702	95	4 x 8	6.36	5.80	6.10
			180		5.76	6.47	6.11
			29	6 x 12	5.98	5.85	5.91
			180		-----	-----	-----

Appendix VII: Stress-Strain Data of Concrete Mixes at 40% of Ultimate

Appendix VII (a): Stress-Strain Data of Concrete Mixes at 40% of ultimate

Mix No.	w/cm	Age (days)	Cylinder Size (in.)	Stress (psi)	Strain (in./in.)	Stress (psi)	Strain (in./in.)
1C	0.33	36	4 x 8	4049	0.0075	4106	0.0077
		64		4121	0.0075	4106	0.0077
		165		4057	0.0065	4151	0.0086
		180		----	----	----	----
2C	0.33	34	4 x 8	4282	0.0061	5151	0.0099
		57		4144	0.0086	4174	0.0085
		106		4053	0.0074	4065	0.0083
		182		4658	0.0076	4115	0.0069
3C	0.33	28	4 x 8	4147	0.0085	4146	0.0086
		114		4037	0.0066	4062	0.0072
4C	0.33	33	4 x 8	4099	0.0085	4100	0.0085
		57		4094	0.0083	4089	0.008
		104		4524	0.0087	4815	0.0099
		180		4018	0.0071	4113	0.0071
5C	0.33	35	4 x 8	4138	0.0065	4189	0.0076
		57		4136	0.0086	4170	0.0082
		104		4532	0.0088	5058	0.0097
		180		4044	0.007	4055	0.0066
6C	0.33	37	4 x 8	4241	0.008	5104	0.0102
		57		----	----	4310	0.0086
		104		4550	0.0081	4528	0.0081
		180		4071	0.0072	4065	0.0071
7C	0.33	28	4 x 8	4875	0.01	4371	0.0093
		56		4077	0.0076	4088	0.0077
		102		4533	0.0079	4541	0.0083
		181		4077	0.0077	4057	0.0072
8C	0.33	35	4 x 8	4780	0.0105	4591	0.0093
		56		4066	0.0084	4132	0.0083
		102		4534	0.0082	4026	0.0075
		180		4063	0.0073	4086	0.0072
9C	0.33	32	4 x 8	4143	0.0084	4164	0.0084
		60		4039	0.0078	4073	0.0082
		90		4050	0.0076	4095	0.0077
		180		4058	0.0072	4123	0.0074
10C	0.33	32	4 x 8	4247	0.0079	4315	0.0096
		60		4045	0.008	4038	0.0078
		90		4068	0.0082	4114	0.008
		180		4102	0.0069	4137	0.0068
11C	0.33	28	4 x 8	4142	0.0086	4139	0.0089
		57		4071	0.0087	4056	0.0076
		118		4037	0.0069	4048	0.0074
		180		4039	0.0073	4369	0.0077

Appendix VII (b): Stress-Strain Data of Concrete Mixes at 40% of ultimate

Mix No.	w/cm	Age (days)	Cylinder Size (in.)	Stress (psi)	Strain (in./in.)	Stress (psi)	Strain (in./in.)
12C	0.33	28	4 x 8	4161	0.0083	4202	0.0089
		57		4061	0.0074	4046	0.0078
		118		4104	0.0072	4069	0.0068
		180		4052	0.0066	4015	0.0066
13C	0.33	31	4 x 8	4111	0.0095	4066	0.0088
		56		4097	0.0086	4125	0.0088
		137		4078	0.0077	4092	0.0072
		180		4087	0.0077	4073	0.0072
14C	0.33	31	4 x 8	4124	0.0094	4099	0.0089
		56		4086	0.0079	4159	0.0079
		137		4114	0.0068	4037	0.0072
		180		4067	0.0073	4057	0.0072
15C	0.33	30	4 x 8	4096	0.0094	4082	0.0096
		57		4050	0.0089	4055	0.0083
		136		4064	0.0073	4163	0.0075
		180		4048	0.007	4069	0.0066
16C	0.33	32	4 x 8	4131	0.0094	4056	0.0086
		57		4110	0.0093	4046	0.0079
		136		4034	0.0079	4048	0.008
		180		4138	0.0077	4076	0.0075
17C	0.33	28	4 x 8	4134	0.0094	4059	0.0081
		58		4097	0.0082	4086	0.0078
		139		4080	0.0074	4049	0.0075
		180		4080	0.0074	4136	0.0075
18C	0.33	28	4 x 8	4163	0.0107	4169	0.0101
		64		4119	0.0092	4016	0.0087
		127		4163	0.0079	4163	0.008
		180		4029	0.0075	4149	0.0073
19C	0.33	38	4 x 8	4010	0.009	4086	0.0085
		58		4089	0.0075	4077	0.0078
		139		4046	0.0072	4065	0.0073
		180		4101	0.0071	4040	0.0075
20C	0.33	---	4 x 8	---	---	---	---
		64		4062	0.0084	4167	0.009
		127		4089	0.0072	4151	0.0075
		180		4100	0.007	4107	0.0068
21C	0.33	28	4 x 8	4172	0.0099	4124	0.0094
		67		4187	0.008	4485	0.0088
		127		4078	0.0066	4132	0.0077
		180		4079	0.0069	4169	0.0079

Appendix VII (c): Stress-Strain Data of Concrete Mixes at 40% of ultimate

Mix No.	Age (days)	Cylinder Size (in.)	Stress (psi)	Strain (in./in.)	Stress (psi)	Strain (in./in.)	Stress (psi)	Strain (in./in.)	Stress (psi)	Strain (in./in.)
22C	32	4 x 8	4118	0.0095	4092	0.0103				
	70		4048	0.0083	4054	0.0082				
	125		4141	0.0077	4136	0.007				
	180		4130	0.0078	4147	0.0077				
23C	29	4 x 8	4132	0.0083	4077	0.0085				
	116		4061	0.0074	4124	0.0073				
	180		4446	0.0071	4076	0.0072				
24C	30	4 x 8	4168	0.0091	4178	0.0082				
	110		4054	0.0072	4067	0.007				
	180		4452	0.0077	4505	0.0075				
25C	30	4 x 8	4084	0.0088	4168	0.0092				
	112		4035	0.0078	4109	0.0075				
	180		4329	0.005	5185	0.0091				
27C		4 x 8								
	96		4026	0.0072	4058	0.0068				
	180		4413	0.0084	4715	0.0091				
28C	31	4 x 8	4109	0.0084	4133	0.009				
	85		4572	0.0084	4618	0.0085				
	180		4170	0.0077	4719	0.0071				
29C	30	4 x 8	4197	0.0088	4444	0.0088				
	180		4514	0.0081	4273	0.0019				
30C	28	4 x 8	4054	0.0094	4092	0.0085				
	116		4030	0.0075	4031	0.0075				
	180		4057	0.0073	4392	0.0082				
31C	56	4 x 8	4691	0.0084	4323	0.008				
	180		4194	0.0075	4510	0.0073				
	28	6 x 12	4055	0.0112	4057	0.0106	4123	0.011	4002	0.0109
	180									
32C	59	4 x 8	4077	0.0078	4548	0.009				
	180		4040	0.0081	4616	0.0072				
	28	6 x 12	4034	0.0114	4048	0.0123	4045	0.012		
	180									

Appendix VII (d): Stress-Strain Data of Concrete Mixes at 40% of ultimate

Mix No.	Age (days)	Cylinder Size (in.)	Stress (psi)	Strain (in./in.)	Stress (psi)	Strain (in./in.)	Stress (psi)	Strain (in./in.)	Stress (psi)	Strain (in./in.)
33C	57	4 x 8	4476	0.0092	4499	0.0085	----	----	----	----
	180		4043	0.007	4673	0.0086	----	----	----	----
	28	6 x 12	4187	0.011	4098	0.0113	4137	0.0119	----	----
	180		----	----	----	----	----	----	----	----
34C	95	4 x 8	4221	0.0073	4057	0.0076	----	----	----	----
	180		4032	0.0077	4181	0.0071	----	----	----	----
	29	6 x 12	4491	0.012	4169	0.0113	4041	0.0107	4186	0.0116
	180		----	----	----	----	----	----	----	----