PERFORMANCE OF HYBRID FIBER REINFORCED SELF-CONSOLIDATING AND NORMAL CONCRETE IN THE STATE OF IDAHO

A Thesis

Presented in Partial Fulfillment of the Requirements for the

Degree of Master of Science

with a

Major in Civil Engineering

in the

College of Graduate Studies

University of Idaho

by

Bikash Sigdel

Major Professor: Ahmed Ibrahim, Ph.D.

Committee Members: Fouad Bayomy, Ph.D., Richard Nielsen, Ph.D.

Department Chair: Patricia J. S. Colberg, Ph.D.

May 2017

AUTHORIZATION TO SUBMIT THESIS

This thesis of Bikash Sigdel, submitted for the degree of Master of Science with a Major in Civil Engineering and titled "PERFORMANCE OF HYBRID FIBER REINFORCED SELF-CONSOLIDATING AND NORMAL CONCRETE IN THE STATE OF IDAHO," has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

Major Professor: ________________________________ Date: ________________
Ahmed Ibrahim, Ph.D.

Committee Members: ________________________________ Date: ________________
Fouad Bayomy, Ph.D.

________________________________ Date: ________________
Richard Nielsen, Ph.D.

Department Chair: ________________________________ Date: ________________
Patricia J. S. Colberg, Ph.D.

ABSTRACT

The first part of this study aims at developing hybrid fiber reinforced self-consolidating concrete (HFRSCC) made with a very high volume of supplementary cementitious materials (SCMs). Self-consolidating concrete (SCC) is a highly workable concrete that can easily flow through heavily reinforced concrete sections without the need for mechanical vibration. The percentages (by volume) of fibers considered were 0.1% and 0.2% hybrid combinations of nylon (PVA) and steel fibers, respectively. Cement was replaced by various percentages of SCMs by up to 70%. The mechanical properties (compressive strength, modulus of elasticity and tensile strength) and unrestrained drying shrinkage of the developed mixtures were evaluated and compared to the standard specifications.

The second part of this study aims at evaluating the mechanical properties (compressive strength, modulus of elasticity, tensile strength, and modulus of rupture), thermal properties and unrestrained drying shrinkage of the paving and structural concrete mixtures being used in the six districts of the State of Idaho. The focus of this evaluation was to develop a material database required for the implementation of the “AASHTOWare Pavement ME Design” (ME) Software which is used to design rigid Portland Cement Concrete (PCC) pavements. The data developed and examples of its implementation in the ME software were conducted, evaluated, and presented.

Keywords: Self-consolidating concrete, fly ash, silica fume, slag, supplementary cementitious materials, hybrid fibers, fresh, mechanical, and durability properties, AASHTOWare Pavement ME Design

ACKNOWLEDGEMENTS

To my advisor, Dr. Ahmed Ibrahim, I am heartily grateful for the inspiration, encouragement, motivation and support he provided me throughout my thesis and graduate studies. Working with him was an opportunity of great learning experience. The patience he had for explaining concepts related to this research and in reading reports written by a non-native English speaker is greatly appreciated. Without his help and continuous support this work would not have been possible. My sincere and profound thanks are due to Dr. Fouad Bayomy and Dr. Richard Nielsen for serving as members of my thesis reviewing committee.

I would also like to thank Sabreena Nasrin for the help she provided during mixing and testing of the specimens. Also thanks to Don Parks for his technical support when needed. This work would not have been possible without their support as well.

I wish to express my gratitude and sincere appreciation to the authority of Sika Corporation for the generous support by providing the fibers and others materials needed for the self-consolidating concrete. Special thanks to Jeremy Chilton, Mark Criswell, Alberto Rey, Jamie M. Gentoso and Ketan Sompura at Sika Corporation. Also, my appreciation to Jesse Espy at Pre-Mix Inc. for providing us the aggregates and cementitious materials for the self-consolidating concrete.

My huge appreciation to Idaho Transportation Department (ITD) for providing the necessary materials and financial support for the concrete mixtures being used in the six districts of the State of Idaho. Special thanks to Dr. Somayeh Nassiri, Milena Rangelov and Dr. Ahmed Muftah for their contribution to develop the PCC characteristics material database.

Acknowledgement is also due to the University of Idaho for the support given to this research through its facilities and for granting me the opportunity to pursue my graduate studies with financial support. I would once again like to thank the University of Idaho for having such a great atmosphere on campus for International students. At the University of Idaho, I never felt like away from home.

DEDICATION

This work is dedicated to my father Shankar Prasad Sigdel, my mother Sabitra Devi Mishra, and all my friends here in Moscow, Idaho and all over the world for their constant prayers, guidance, encouragement and invaluable support throughout my studies. Without their moral support, this would not have been possible.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

1.1 PROBLEM STATEMENT

Self-consolidating concrete (SCC) is a highly workable concrete that can easily flow through heavily reinforced concrete sections without the need for mechanical vibration. The development and use of SCC with a high content of supplementary cementitious materials (SCMs) is believed to help reduce both waste and energy consumption. The inclusion of fiber in the SCC should further enhance its mechanical and durability properties. However, due to the lack of data on the long-term performance of hybrid fiber reinforced self-consolidating concrete (HFRSCC), there has been concern regarding structural and durability performance. The high cement requirement and the addition of chemical admixtures to attain the self-consolidating properties may discourage structural and pavement engineers from using SCC in normal construction practice. Therefore, to promote the use of SCC, research in HFRSCC mixtures with high content of SCMs as partial replacement of Portland cement is needed. This could be achieved by conducting an experimental study on SCC mixtures with cement replaced by various percentages of SCMs up to 70% and adding hybrid fibers to develop highly workable, strong, durable concrete mixes with acceptable early-age compressive strength.

Furthermore, as the AASHTOWare Pavement ME Design software is being implemented nationwide to design the flexible and rigid pavements, the Idaho Transportation Department (ITD) has actively initiated the basic preparation work needed to implement the ME software to design flexible pavements. To date, ITD has developed a material database and training modules and implementation manual that enable the AASHTO design software to be used for flexible pavement design. However, ITD has not yet started similar steps for the design of rigid concrete pavements. Hence, the evaluation of the mechanical, thermal and durability properties of the paving and structural concrete mixtures being used in the six districts of the State of Idaho is needed to create a database to start implementing the AASHTOWare Pavement ME Design software to design rigid pavements in Idaho.

1.2 OBJECTIVE OF RESEARCH

The primary objective of this study is to develop a hybrid fiber reinforced self-consolidating concrete (HFRSCC) mixture with a high content of supplementary cementitious materials (SCMs) replacing partially the Portland cement. This can be achieved by preparing various self-consolidating concrete mixtures with high content of SCMs and different content of steel and nylon (PVA) fibers. Then, compare their fresh properties, mechanical properties, and durability properties with standard specifications. The fresh properties include slump flow and T_{50} with and without J-ring. The mechanical properties include compressive strength at different ages, tensile strength and modulus of elasticity. Unrestrained drying shrinkage was also measured to evaluate concrete durability.

A secondary objective of this study is to evaluate the mechanical, thermal and durability properties of the paving and structural concrete mixtures being used in the six districts of the State of Idaho. The mechanical properties for these mixtures include compressive strength, tensile strength, modulus of elasticity and modulus of rupture at different ages. The coefficient of thermal expansion and unrestrained drying shrinkage was also measured to evaluate concrete thermal and durability property, respectively. The focus of this evaluation is to develop a database required for the implementation of the "AASHTOWare Pavement ME Design" (ME) Software which is used to design rigid Portland Cement Concrete (PCC) pavements. This can be achieved by preparing the paving and structural concrete mixtures being used in the six districts of the State of Idaho and testing them at different ages.

1.3 THESIS OUTLINE

The thesis is divided into two parts: the first part (Chapter 2 to 6) presents the development of the self-consolidating mixtures and the second part (Chapter 7) presents the evaluation of the properties of the normal concrete mixtures used by Idaho Transportation Department (ITD) in Idaho for the rigid pavements and bridges.

Chapter 2: "INTRODUCTION TO SCC MIXTURES": This chapter provides the introduction and background of SCC and HFRSCC.

Chapter 3: "LITERATURE REVIEW FOR SCC MIXTURES": This chapter summarizes relevant previous and existing research conducted on SCC, HFRSCC, highly SCMs used concrete, their fresh, mechanical, and durability properties.

Chapter 4: "EXPERIMENTAL PROGRAM FOR SCC MIXTURES": This chapter covers experimental plan and setup for the SCC mixtures along with the materials used and their properties. It also provides proportions of the concrete mixtures used for this study and testing procedures.

Chapter 5: "RESULTS AND DISCUSSIONS FOR SCC MIXTURES": This chapter describes all the test results for the SCC mixtures; fresh, mechanical and durability properties studied in this research.

Chapter 6: "SUMMARY AND CONCLUSIONS FOR SCC MIXTURES": This chapter presents the conclusion drawn from chapters 5. Also, recommendations are provided in this chapter for future researches.

Chapter 7: "PORTLAND CEMENT CONCRETE MATERIAL CHARACTERIZATION FOR AASHTOWARE PAVEMENT ME DESIGN IMPLEMENTATION IN IDAHO": This chapter presents the background information, materials requirement, properties evaluation plan, and the fresh, mechanical, thermal and durability properties of the paving and structural concrete mixtures being used in the six districts of the State of Idaho. Also, data developed and examples of its implementation in the ME Software is included in this chapter.

CHAPTER 2: INTRODUCTION TO SCC MIXTURES

2.1 GENERAL

Concrete is mixtures of aggregate (sand, crushed rock or gravel) held together by a binder of a cementitious paste generally made up of Portland cement and water but may also contain supplementary cementitious materials (SCMs) such as fly ash, silica fume, slag and chemical admixtures. In this booming construction industry, due to the huge infrastructural advancement phase, concrete is the widely-used material around the globe. Its use in countless architectural eyesores, from skyscraper to parking garages to highways to bridges, and its feasibility, durability, versatility, sustainability and economy had made the concrete remarkably good building material.

Due to the abundant use of concrete, over six billion tons per year currently and forecasted to be 18 billion tons annually by 2050, the cement production contributes to more than 7 % of the anthropogenic global Carbon dioxide (CO_2) production. During cement and concrete production, issues like CO_2 emissions along with the use of energy, air pollution due to dust, gases, noise and vibration when operating machinery and during blasting in quarries, aggregate consumption in a great amount, depleting natural resources, demolition of waste concrete, and filler requirements causes environmental impact during the manufacturing process. Amidst, the CO_2 emission is considered to be the most harmful to the environment. The reality shows that every ton production of Portland cement releases nearly one ton of CO_2 into the atmosphere [1].

Hence, current situation describes a desire for an enhanced concrete product that can maintain the position of concrete as the dominant structural material while keeping the environment clean with low production cost and reducing the need for additional concrete consumption in current and future years.

2.2 HYBRID FIBER REINFORCED SELF-CONSOLIDATING CONCRETE

Self-consolidating concrete (SCC) is one of the relatively new techniques to address concrete placement in congested reinforced concrete members. It is a highly workable concrete that does not require mechanical vibration and can easily flow through heavily reinforced concrete sections. Since the development of SCC in the late 1980's, it represents one of the most significant recent advances in concrete technology. The use of chemical admixtures such as High-range water reducer (HRWR) and viscosity modifying admixtures (VMA) are generally recommended due to the high workability requirement of SCC [2]. In addition, the development of SCC requires using higher quantities of fine materials (i.e. cement and fine aggregate) in the mixture and using Portland cement in large quantity leads to a higher cement production and therefore, higher emission of CO_2 in the atmosphere. More importantly, most of today's industrial-by-product cementitious materials, such as fly ash, slag, and silica fume are still dumped in the landfills. The use of such materials in large quantities as partial replacement of cement in the concrete industry will not only reduce wastes but will also preserve our natural resources by significantly reducing cement production and CO_2 emission.

Hybrid fiber reinforced self-consolidating concrete (HFRSCC) is simply combining the concepts from the field of self-consolidating concrete with fiber reinforced concrete. Due to this combination, we can have the advantages of both self-compacting and fiber inclusion, providing improved mechanical properties such as tensile strength, energy absorption, and tensile strain in comparison to the conventional concrete. The presence of fibers in concrete decrease the workability of the concrete for which HFRSCC is a solution. Therefore, HFRSCC with high content of SCMs can be an enhanced concrete product that can maintain the position of concrete as the dominant structural material with respect to the environmental, economy and structural concern.

CHAPTER 3: LITERATURE REVIEW FOR SCC MIXTURES

3.1 INTRODUCTION

Self-consolidating concrete (SCC) is classified as an advanced construction material because of its flowability, which allows it to fill forms without mechanical vibration. SCC can be placed in structural elements with congested reinforcement, such as in beam-column joints or in seismic resistant structures. This type of concrete achieves full compaction without any external or internal mechanical vibration. SCC has a high level of deformability, and an ability to fill narrow and congested formwork while maintaining a relatively high viscosity and resistance to segregation. Once SCC has cured or hardened, it has the same or superior engineering properties and durability compared to conventional concrete. Particular benefits of SCC include [3], [4]; 1) it requires less labor and equipment in its production and placement, 2) its mechanical and engineering properties are independent of skill of the vibrating crew, 3) it can be placed more quickly even in highly reinforced sections and complex formworks, 4) it can be placed with less number of spreading points which will reduce transit trucks and pump lines movements to place concrete hence expediting the construction process, 5) the quality of the finished concrete is improved and requires fewer on-site repairs, 6) construction noise is reduced, and 7) the construction environment is safer since it does not need to be vibrated [2], 8) it allows flexible reinforcement detailing, 9) it reduces the need for surface finishing and leveling materials, 10) it lowers overall costs, and 11) it contributes to green construction and sustainable infrastructures.

The main challenge in the development of SCC is to achieve a balance between a highly flowable concrete (for ease of placement) and low relative viscosity (to avoid segregation of aggregates, cement and water). It requires experience and judgment to achieve this balance. Increasing the water/cement (w/cm) ratio can provide the necessary flowability but will lead to a lower strength, higher segregation, and less durable concrete. The development of SCC requires using higher quantities of fine materials (i.e. cement and fine aggregate) in the mixture and use of HRWRA and VMA. Increasing the proportion of Portland cement in the concrete mixture increases the CO_2 emission to produce the concrete. Fortunately, finely ground, inert and pozzolanic/hydraulic mineral admixtures can replace some of the Portland cement in the SCC to improve and maintain the cohesion and segregation resistance [3].

Mineral admixtures that are of interest in this study include; fly-ash (FA), ground granulated blast furnace slag (S), and silica fume (SF). These admixtures are generally industrial-by-products and would otherwise be disposed of in a landfill. Using them in SCC will reduce waste in land fills and most importantly reduce the amount of cement required contributing to a significant reduction in the development cost of SCC as well as the amount of CO_2 released into the air.

The inclusion of fibers in SCC is a relatively recent practice that combines the benefits of SCC technology with the advantages of the fiber addition to a brittle cementitious matrix [5]. Steel fibers are added to the SCC in limited proportions to increase its tensile strength. In proper proportions, steel fibers can improve the concrete's compressive strength, as the limiting strain of reinforced concrete section in design is the tensile strain. The addition of hybrid blend of steel fibers and polyvinyl alcohol (PVA) fibers to SCC can improve the tensile strength, energy absorption, and most importantly, the tensile strain of the concrete. The addition of SCMs is intended to improve the durability of the SCC by reducing shrinkage, and permeability.

In summary, HFRSCC is a concrete material which has a combination of steel and PVA fibers and in its fresh state flows into the interior of formwork, filling and passing through the heavy reinforcements, flowing and consolidating under its own weight [5]. Previous investigations [6], [7], have conducted research on the use of hybrid fibers in SCC, yet, little research has been done on replacing cement with very high volume of supplementary cementitious materials *and* using hybrid fibers in SCC.

3.2 DEVELOPMENT OF SELF-CONSOLIDATING CONCRETE

SCC was first introduced in Japan by Japanese researchers in late 1980s and in Europe shortly thereafter. For example, SCC was used in civil works for transportation networks in Sweden in the mid-1990s [3]. The main motivation to develop SCC was the shortage of skilled labors which was directly affecting the quality of concrete structures in the country at that time [8]. Concrete members' design led to smaller and more heavily reinforced sections, which led to congested sections and connections. Placing conventional concrete in such members without skilled labor can lead to problems such as honeycombing and voids in the concrete surfaces.

Poor concrete consolidation leads to increase in the internal concrete void network which decreases durability and shortens the life of the structure. The high flowability of SCC avoids these issues.

Okamura initiated research on SCC in 1986 [8]. Ozawa (1988) further studied the characteristics of SCC suggested by Okamura including fundamental parameters like workability and viscosity and was able to develop the prototype of SCC using materials available on the market by including different types of superplasticizer [8]. These developments led to a rapid increase in the use of SCC in the early 1990s in Japan. By the year 2000, 520,000 yd^3 (400,000 m^3) of SCC was used for prefabricated and cast-in-place concrete in Japan [9]. The SCC made its way towards Europe after the European countries formed a large consortium in 1996 with a project titled “Rational Production and Improved Working Environment through using Self-Compacting Concrete” [9]. Within that time, SCC has been used in several bridges, walls, tunnel linings, and other commercial projects in Europe.

In North America, the use of SCC has been implemented in the concrete industry since early 2000, especially within the precast pre-stressed concrete industry [10]. Several researchers such as [9], [11]–[13] has conducted various studies to investigate the properties of SCC, to define its characteristics and requirements for the raw materials used, to develop a standard procedures for mixture design and proportions, and to establish a series of certified laboratory testing methods necessary to produce and test SCC mixtures.

According to the Precast/Pre-stressed Concrete Institute [14], SCC is defined as follows:

“A highly workable concrete that can flow through densely reinforced of complex structural elements under its own weight and adequately fill voids without segregation or excessive bleeding without the need for vibration to consolidate it”.

The American Concrete Institute [4] defined SCC as follows:

“Highly flowable, non-segregating concrete that can spread into place, fill the formwork, and encapsulate the reinforcement without any mechanical consolidation”.

The American Society for Testing and Materials [15] however, defined SCC as:

“Concrete that can flow around reinforcement and consolidate within formwork under its own weight without additional effort, while retaining its homogeneity”.

Most of the studies found in the literature were focused on the improved trustworthiness of SCC and prediction of its properties, improved long-term durability, and strength at various ages during the design life of structures and to permit faster construction and increased productivity [13], [16]–[18].

3.3 HYBRID FIBER REINFORCED SELF-CONSOLIDATING CONCRETE WITH A VERY HIGH VOLUME OF SCMS

Fiber reinforced concrete (FRC) is a cement-based composite that usually contains discrete fibers in random orientation. Conventional concrete is weak under tensile loading and its reinforcement with fibers can enhance these mechanical properties by preventing or controlling the initiation, propagation, or coalescence of cracks. There are different types, shapes, and sizes of fibers usually used in concrete, including steel, synthetics, glass, and other natural materials. However, steel fibers are the mostly used to improve the structural propertied of the concrete and synthetic fibers are mostly used to control the plastic-shrinkage cracks in concrete slabs [19].

The inclusion of fibers mainly enhances post-cracking properties of concrete and provides a more ductile material behavior. The FRC have high ductility because of the fibers’ capability to bridge and transfer the tensile stress across the cracked section and their potential to reduce the crack depth. The reduction of crack depth mainly depends on the amount of fiber added, their physical properties such as surface roughness and chemical stability, and mechanical properties such as tensile strength [19], [20].

The fiber reinforced self-consolidating concrete (FRSCC) is a concrete mixture having the advantages of both SCC with the fibers to enhance and increase its post-cracking characteristics [5]. In recent times, steel fibers have been added to the SCC to increase its tensile strength in proportion to its compressive strength because the limiting strain of reinforced concrete section in design is the tensile strain. In addition, the use of FRSCC in interesting structural applications such as precast and pre-stressed elements, sheet piles, tunnel segments are listed within the literatures [21].

Adding fibers to SCC improves mechanical characteristics and ductility compared to conventional concrete; however, it reduces the workability of SCC because of the fibers' elongated shape and large surface area. Thus, the volume of fibers to be added is limited depending on the fiber type and the composition of SCC mix. The optimum amount of the fibers to be used in SCC should be selected to have the least effect on the workability while maintaining good flowability, passing ability and resistance to segregation [22]. Very limited data are available on the exact percentage of fibers to be added to SCC mixtures. Consequently, mixtures were developed in a trial and error fashion.

The addition of steel fibers and PVA fibers in concrete give rise to hybrid fibers, which improve the mechanical properties such as tensile strength, energy absorption, and most importantly, the tensile strain. On the other hand, the addition of SCMs aims to improve its durability properties, such as shrinkage, and permeability. Ibrahim et al. [2] conducted research on the feasibility of developing high-performance SCC with a high content of SCMs and researchers [5]–[7], [23] have conducted research on the development of hybrid fibers in SCC with partial replacement of cement with SCMs. However, few studies were found in the literature on replacing cement with a very high volume of SCMs *and* using hybrid fibers in SCC.

Ibrahim et al. [2] investigated the feasibility of developing ultra-strength high-performance SCC by replacing up to 70% of Portland cement by a combination of different SCMs which includes ground granulated blast furnace slag, fly-ash, and silica fume.. The properties of fresh concrete such as flowability, deformability, filling capacity, air content, and resistance to segregation were investigated. The investigation concluded that ultra-strength high-performance SCC could be developed with low water-cement ratio (w/cm) and up to 70% of cement replaced by SCMs having properties superior to those of the control mixtures made with 100% Portland cement.

Hossain et al. [23] studied the influence of PVA, and hybrid fibers on the rheological properties of SCC using different concrete mixes, fiber types and partial replacement of Portland cement with furnace blast slag. The properties of the concrete tested included slump flow, passing ability using L-box, segregation index, etc. It was observed that the properties of the fresh concrete depend on a combination of factors that cannot be singly isolated from each other. These factors are based on mixture design, the size of hybrid fibers and dosage of viscosity modifying admixtures (VMA), amongst others.

Hossain et al. [7] extended their study on hybrid steel fibers in SCC to observe the mechanical properties and fracture energy of such mixtures. A high increase in fracture energy of the specimen tested was observed, which was much higher than that observed in compressive and tensile strength of the specimen tested. The increased strength and fracture energy of hybrid fibers SCC can reduce the amount of tensile reinforcement in RC-structures built with hybrid fibers SCC, as well as provide a concrete with high absorbing energy.

Aslani & Nejadi [5] carried out a test program to develop information about the mechanical properties of FRSCC. Four SCC mixes– plain SCC, steel, polypropylene, and hybrid FRSCC – with partial cement replacement by fly ash and ground granulated blast furnace slag were tested to determine their mechanical properties include compressive and splitting tensile strengths, moduli of elasticity and rupture, compressive stress–strain curve, and energy dissipated under compression. Relationships are established to predict the compressive and splitting tensile strengths, moduli of elasticity and rupture, compressive stress–strain curve, and energy dissipated under compression.

Jen et al. [6] investigated the Self-Consolidating Hybrid Fiber Reinforced Concrete mix to provide an optimal structural material for construction in which concrete might be expected to face tension, compression and bending as part of a common service load designed to withstand high levels of deformation under maximum credible earthquake or similar design scenarios. The ductility response of such concrete to severe loading was then investigated through a comparison with conventional concrete by conducting reinforced compression and tensile tests. In both scenarios, the presence of hybrid fiber reinforcement is shown to improve internal confinement and tension stiffening, for compression and tension loading respectively, which allow for a significantly improved post-cracking response.

3.4 MATERIALS USED IN THE DEVELOPMENT OF SCC

The basic materials required for the development of a SCC mixture are similar to conventional concrete (i.e. coarse and fine aggregates, Portland cement, and water) except that a SCC mixture contains less coarse aggregate and a greater volume of fine powder (cement and filler particles smaller than 0.125 mm) [24]. Use of additional chemical admixtures such as HRWR and VMA are required to avoid a high water to cement ratio (w/cm) and to maintain high flowability and moderate viscosity. In addition, cementitious, and pozzolanic admixtures such as fly ash (FA), ground granulated blast furnace slag (S), limestone powder (LP), and silica fume (SF) have been successfully used as SCMs along with Portland cement or as a partial replacement of Portland cement in SCC mixture.

3.4.1 Portland Cement

Portland cement (PC) is the most important ingredient required in any concrete mixture. It chemically reacts with water to form a binding gel that with time continues to hydrate and glues all concrete components together to form a rock-like concrete matrix. Several types of PC have been approved by ASTM standards [25] and have been successfully used in today's construction. However, the most common type of normal concrete construction is ASTM Type I. All types of cement contain the four major chemical oxides: Tri-calcium silicate hydrate (C_3S), di-calcium silicate hydrate (C_2S), Tri-calcium aluminate (C_3A), and Tetracalcium aluminoferrite (C_4AF). The oxides that are responsible for strength development are C_3S and C_2S while C_3A affects workability and durability. Cement oxides chemically react with water to produce new hydration products, mainly calcium silicate hydrate (C-S-H) and calcium hydroxide (C-H). The C-S-H microstructure is the product responsible for strength while C-H in large quantity may negatively affect concrete durability. The selection of the appropriate type of cement for a certain application depends on the overall requirements of concrete, such as workability, strength, and durability. For example, cement having a large amount of C_3S gives high early strength while cement C_3A content greater than 10% reduces workability [3].

3.4.2 Pozzolanic and Cementitious Materials

The term "powder" in SCC mixtures is the total content of Portland cement and supplementary cementitious materials (SCMs). SCMs are usually added as partial replacements of Portland cement to increase the paste volume and achieve the desired workability and deformability of the concrete mix. Studies show that materials with pozzolanic properties slowly react with calcium hydroxide (C-H), a by-product of Portland cement hydration, to form more of the hydration product C-S-H, thus enhancing concrete durability and strength. Researchers have also shown that using SCMs in appropriate amounts enhances both workability and durability without sacrificing the early strength [10].

SCMs used in the development of SCC include fly ash (FA), limestone powder (LP), ground granulated blast furnace slag (S), and silica fumes (SF). Slag has hydration properties that qualify them to be considered cementitious materials, whereas silica fume and fly ash are classified as pozzolanic materials. Silica fume is normally used in small amount mostly in pre-cast concrete, but the use of slag and fly ash has noticeably increased as a supplementary cementitious materials [26]. Pozzolanic materials do not hydrate by themselves but react with soluble alkali and calcium hydrate in the presence of humidity. The concrete containing pozzolanic material requires additional curing time compared to conventional concrete due to its slow hydration rate [10]. Concrete mixtures containing pozzolanic materials usually develop low early strengths; however, they have been found to improve the fresh properties (flowability, passing ability and deformability) of concrete and those of the hardened concrete at later ages [2], [27].

3.4.2.1 Ground Granulated Blast Furnace Slag

Ground granulated blast furnace slag, a by-product of the steel industry, is generally used as a partial replacement of Portland cement in the range of approximately 40% to 60% of the total SCMs in conventional concrete mixtures [10]. The consumption of slag in U.S. was about 10.5 million metric tons in 2001 out of which 58% was utilized in the states of Illinois, Indiana, Michigan, and Ohio. The average cost of slag was about $10.67 per metric ton, totaling 112 million dollars. The Mid-Atlantic States of Maryland, New York, Pennsylvania and West Virginia consumed 29% whereas other states including, Alabama, California, Kentucky, Mississippi and Utah consumed the remaining 13% [28].

GGBFS usually reacts with $Ca(OH)_2$ in the presence of water to produce more C-S-H which strengthen the cement matrix and enhancing concrete durability [28]. Lachemi et al. [29] also reported that concrete mixtures made with 50% to 70% cement and 30 to 50% slag generally have lower early strengths and higher ultimate strengths than conventional concrete.

In addition, Russell [30] reported that the use of slag lowers the permeability of concrete and could be used to improve the strength gain at ages later than 28 days. Similar results were also observed by Sobolev [31] who stated that concrete mixtures made with 50% cement by mass replaced by GGBFS had very high chemical and thermal resistance. Ozyildirim [32] investigated the durability of concrete made with slag where shrinkage and flexural strengths were investigated in a jointed plain concrete pavement. Two of the mixtures contained 30% GGBFS as partial replacement of cement and the third contained Class F fly ash. The maximum w/cm ratio was 0.5. The 28-day flexural strengths were similar for all mixtures, but after 60 days the flexural strength of concrete mixtures containing slag was higher than for mixtures containing fly-ash. The shrinkages values for the mixtures containing slag, however, were slightly greater than those of the mixture containing fly ash.

3.4.2.2 Fly Ash

Fly ash is a pozzolanic material consisting of the "finely divided residue that results from the combustion of ground or powdered coal" as defined by [33]. It reacts chemically with calcium hydroxide produced during the hydration process of Portland cement to form an additional cementitious compound. Concrete mixtures containing adequate proportion of fly ash can have equivalent or higher 28-day compressive strengths when compared to normal concrete. Due to the slow pozzolanic reaction, fly ash concrete continue to gain strength beyond 28 days exceeding that of normal Portland cement concrete in some cases [34]. In general, adding fly ash to concrete mixtures improve workability, durability and reduces bleeding, hence requiring less water [17]. The use of fly ash is usually limited to 25% to 35% in conventional mixtures. However, Mehta [34] suggested that fly-ash should constitute a minimum of 50% of the cementitious material for the concrete mixture to be sustainable i.e. achieving a balance between environment, economy and society.

Naik and Singh [35] investigated the effect of fly ash obtained from various sources with various proportions from 0 to 100 percent by mass of the cementitious medium. The fly ash to cement ratio was kept at about 1.25. The research concluded that the initial and final times of setting of the concrete mixtures were greatly affected by both the source of the fly ash and the fly ash content. Also, the times of setting was studied and concluded that the setting time were generally delayed up to a certain level of cement replacement with fly ash, about 60 percent, beyond which rapid setting occurred.

3.4.2.3 Silica Fume

Silica-Fume, also known as condensed silica fumes or micro silica is a by-product of high-purity quartz coal used in electrical furnaces in the production of silicon and ferrosilicon alloys [36]. It has chemical and physical properties that make it a very reactive pozzolan and concrete mixtures containing silica fume usually develop very high strength and durability. Although silica fume is normally used as an additive in concrete at proportions of 7% to 10 % by weight, but it can be used up to 15% by weight of cement. It is expensive and requires high water content; thus, its use must be combined with the use of HRWRA.

The addition of SCMs does not reduce the early strength of concrete [10]. These materials can, therefore, be used in higher proportions up to 60% to 70%. The use of some materials, such as slag and silica fumes will increase the production cost of the concrete mixture, but they will reduce the overall lifecycle cost of the structure. Using such waste materials to replace up to 70% of cement in the concrete industry will contribute to green concrete and shift towards sustainable development.

3.4.3 Aggregates

Well-graded coarse aggregates having a maximum size of 19 mm (¾ inches) are used in the development of SCC mixtures. However, some researchers recommend limiting the maximum aggregate size to 12 mm (½ inch) or in some cases to 9.5 mm (3/8 inches) due to the use of SCC in the congested reinforcement sections [10]. Coarse aggregates with a maximum size of 4.75 mm (No. 4) to 12 mm (½ inch) and quantities varying from 790 Kg/m^3 (1335 lb/yd^3) to 860 kg/m^3 (1454 lb/yd^3) have been used in SCC mixtures with satisfactory results [16]. It is also recommended to keep the coarse aggregate to fine aggregate ratio equal to or less than one in SCC mixtures [3]. Okamura [37] suggested that if the coarse aggregate content of the SCC mixture exceeds a certain limit, the concrete might be less deformable independently of the viscosity of mortar. Mata [10] also suggested that using less amount of coarse aggregate in a SCC mixture is more effective than decreasing the sand-to-paste ratio to maintain an acceptable passing ability in heavily reinforced sections.

The aggregate ratio (fine aggregate volume/total aggregate volume) plays important role in successful design of SCC mixture. It has been reported that increasing the aggregate ratio improves the rheological properties of SCC mixtures [38]. Bui et al. [39] also proposed a rheological model for SCC relating the paste rheology to the average aggregate spacing and diameter. They concluded that if the aggregate spacing is large, it requires a lower flow and higher viscosity of the paste for SCC to achieve satisfactory deformability and segregation resistance. Coarse aggregates containing clay and dirt seem to cause creep and shrinkage. Thus, aggregates must be clean and free of any organic materials with a proper temperature to be successfully incorporated in SCC mixtures [26]. Moisture content and absorption of aggregates (fine and coarse) should always be closely monitored and must be considered to produce SCC of consistent quality [3].

3.4.4 Chemical Admixtures

Chemical admixtures have long been recognized as important components of concrete mixtures. They are generally used to improve concrete performance and enhance its durability. ACI 116R [40] defines the term admixture as "a material other than water, aggregates, hydraulic cement, and fiber reinforcement, used as an ingredient of a cementitious mixture to modify its freshly mixed, setting, or hardened properties and that is added to the batch before or during its mixing."

ACI 212 [41] also stated that "chemical admixtures are used to enhance the properties of concrete and mortar in the plastic and hardened state. These properties may be modified to increase compressive and flexural strength at all ages, decreases permeability and improve durability, inhibit corrosion, reduce shrinkage, accelerate or retard initial set, increase slump and workability, improve pumpability and finishablity, increase cement efficiency, and improve the economy of the mixture. In certain instances, the desired objectives may be best achieved by changing mixture's proportion in addition to proper admixture usage". Generally, two types of chemical admixtures are commonly used in the production of SCC mixtures; HRWR and VMA. In the following section, a brief description of HRWR will be introduced.

3.4.4.1 High Range Water Reducers (HRWR)

The primary difference between HRWR and conventional water reducing admixtures is that HRWR admixtures, which are often referred to as superplasticizers, reduce the amount of water required by more than 30%, without side effects of excessive retardation [42]. Mata [10] also stated that the use of HRWRA is indispensable to successfully achieve a SCC.

The main objective of using HRWR admixtures is to produce a flowable concrete with very high slump flow, which can be used in congested reinforcement sections and in places where adequate consolidation cannot be achieved through vibration [24]. The strength of hardened concrete containing HRWR admixtures is normally higher than that of concrete made with lower w/cm alone. SCC mixtures containing HRWRA typically have a low water to cement (w/cm) ratio. Thus, shrinkage and permeability of such concrete may be reduced and its overall durability may be increased [42].

Advantages of using HRWR admixtures in SCC may be summarized as follows:

1. Significant water reduction,
2. High strength with increased workability,
3. Reduced effort and labor required for placement with reduced equipment cost,
4. More rapid rate of early strength development, and
5. Increased long-term strength and reduced permeability.

3.5 MATERIAL QUANTITIES REQUIRED FOR HFRSCC

The following proportions and quantities are needed to produce high-performance sustainable SCC:

1. A minimum of 50% to 70% SCM by mass of the total cementitious material [34].
2. A low water content, generally ranging between 170 Kg/m^3 to 176 Kg/m^3 [38]. The water content should not exceed 200 Kg/m^3 [3].
3. A total powder content (Cement + SCM) from 400 Kg/m^3 to 600 Kg/m^3 [3].
4. A cement content, generally no more than 200 Kg/m^3 is desirable [34].
5. A coarse aggregate content, generally between 700 Kg/m^3 to 900 Kg/m^3, which should be 28% to 35% by volume of the mixture [3].
6. An aggregate ratio (i.e. ratio of coarse aggregate to total aggregate) in the range of 50% to 57% by volume of the mixture [38].
7. A dosage of chemical admixtures of 1.8% by mass of the total powder content [38]. However, the dosage depends on the product [24].
8. A higher workability reduction/viscosity increase due to the inclusion of PVA limits the use of PVA by about 0.125% by volume whereas for the steel fibers can be up to

0.3% by volume. For the hybrid mix, the workability/rheology depends on the types and dosages of fiber and the interaction and synergic properties between different fiber types [23].

3.6 CHARACTERISTICS AND REQUIREMENTS OF FRESH SCC

A concrete mixture can be classified as SCC only if it meets the following three basic characteristics [3], [4], [16],

1) High deformability,
2) High passing ability, and
3) High segregation resistance.

3.6.1 High deformability

Deformability of concrete is defined as concrete's ability to undergo changes in shape under its own weight. High deformability is required in SCC mixtures so that fresh concrete can spread uniformly into all spaces within the formwork and between reinforced bars [10]. It is important to minimize solid particles (aggregates) friction in the mixture to have a required deformability. Thus, a proper design of SCC mixtures requires a reduction in the coarse aggregate content which is balanced by increasing the paste volume to have a required deformability [16].

Deformability of fresh concrete is directly proportional to the deformability of the paste. HRWRA increase the deformability of the paste and decrease the internal friction of solid particles without increasing the w/cm [10]. The deformability of the SCC mixture is usually determined by performing the slump flow test and/or the V-funnel test on the fresh concrete.

3.6.2 High Passing Ability

Passing ability is the ability of SCC mixture to flow through obstacles and small openings, such as congested reinforcement under its own weight. Blockage in concrete members could occur due to the collision and contact between the solid particles themselves or between the solid particles and the reinforcing bars. Hence, the size of the coarse aggregate content is an important factor in the design of SCC mixtures, which is directly related to concrete passing ability [10]. Self-consolidating concrete mixtures having high deformability, but insufficient cohesiveness, may not distribute uniformly throughout the formwork. This can result in aggregate segregation, which can also lead to blockage when the concrete is passing through congested reinforcement. The passing ability of a SCC mixture is usually determined using U-Box, L-Box and/or J-Ring tests.

3.6.3 High Segregation Resistance

Self-consolidating concrete is considered to have high segregation resistance if a uniform composition of the mixture's ingredients can be maintained throughout the process of mixing, transporting and placing while maintaining high deformability and high passing ability. Khayat [11] stated that sufficient cohesiveness can be achieved by adding a dosage of VMA along with HRWR to control bleeding, segregation and surface settlement. Others suggested that an alternative approach to achieve adequate cohesiveness in SCC is to reduce the free water content and to increase the volume of sand and cement paste [10]. The segregation resistance ability of SCC mixture can be evaluated using the segregation index (slump flow test), the segregation column test, and/or the sieving test.

3.7 EVALUATING THE PROPERTIES OF SELF CONSOLIDATING CONCRETE

For quality control purposes, standardized test methods are usually performed to evaluate the properties of any complex material. The quality of SCC is usually validated using standard tests at several stages: before concrete placement or during mixing (i.e. fresh properties), after concrete is hardened (i.e. mechanical properties), and long-term properties (i.e. durability). The following sections explain the standard tests used to evaluate the properties of SCC at all stages.

3.7.1 Fresh Properties

In June 2001 ASTM Committee C09.47 "Concrete and Concrete Aggregates" took the task of developing testing procedures for SCC. The slump flow and the J-Ring tests are the most widely used and accepted test methods for fresh SCC [10]. Other testing methods that are used to assess the fresh properties of SCC include the L-Box Test, the U-Box Test, T50 Slump Flow Test, the Column Test, the V-funnel Test, and the Orimet Test.

3.7.1.1 Slump Flow and T_{50} Tests

The main aim of the slump flow test is to measure the plasticity and to investigate the filling ability of fresh SCC. It is the most commonly used test both in the laboratory and in the field. This test usually measures two parameters: flowability and flow time T_{50} (optional). The former indicates the free, unrestricted deformability and the latter indicate the rate of deformation within a defined flow distance [3], [4].

The equipment used for performing the slump flow test is the same as for the conventional slump test. The method differs from the conventional slump test by the fact that the inverted cone is used, the concrete sample placed into the mold is not rodded and when the slump cone is removed the slump collapses [43]. The test comprises of completely filling an inverted slump cone with the fresh concrete right after mixing. During this process, no vibration or rodding is done. The cone is then raised vertically and the concrete is allowed to flow under its own weight, without any hindrance. The diameter of the concrete pie is then measured in two perpendicular directions and the average of the two diameters is recorded as slump flow of that mixture. If the measurement of the two perpendicular diameters differs by more than 50 mm (2 inches), the test is considered as invalid and must be repeated. Along with the spread, the time taken for the concrete to reach 50 cm (20 inches) is measured. The acceptable flow time, T_{50} is 2 to 5 seconds [3], [4], [10].

Several ranges for slump flow values exist for the concrete mixture to be accepted as SCC mixture depending on testing standards. The acceptable range of slump flow for SCC per ASTM is 450 to 750 mm (18 to 30 inches). EFNARC [3] has an acceptable range of 650 to 800 mm (25 inches to 31 inches). In general, a minimum spread value of 500 mm (20 inches) is required for the concrete mixture to be classified as SCC.

3.7.1.2 J-Ring Test

The J-Ring test is performed to investigate both the filling ability and the passing ability of SCC. The J-ring is a 25 mm (1 inch) wide by12.5 mm (½ inch) thick metal ring with a central diameter of 300 mm (12 inches) and 16 steel bars attached to the ring perimeter spaced at 16 mm (5/8 inches). It is used in combination with the slump cone. This test method is suitable for both laboratory and field testing.

The inverted slump cone is placed concentrically in the J-ring and filled with freshly mixed concrete without rodding or vibration. The cone is then raised vertically and the concrete is allowed to spread under its own weight, passing through the steel bars. The ring is then removed and the mean diameter of the spread is recorded. Per EFNARC [3] the difference in the slump flow values with and without the J-ring should not be greater than 10 mm (0.4 inches). However, ASTM has an acceptable range of 25 mm (1 to 2 inches).

3.7.1.3 Segregation Resistance

Segregation is defined as the separation of large and dense aggregate particles from the mortar matrix during concrete mixing, placing, and finishing [44]. If the concrete mixture was not properly designed to resist segregation, honeycombing might occur and the hardened concrete might not have homogeneous properties throughout. The resistance of SCC to segregation is usually evaluated using several test methods including the segregation column test, the slump flow test, and GTM screen stability test.

3.7.2 Mechanical Properties

3.7.2.1 Compressive Strength

The compressive strength is the most important factor in the design of concrete members. Engineers base their structural design of reinforced concrete members on the compressive strength unless other requirements are necessary. The test is simple and consists of filling concrete cylinders with fresh concrete very soon after mixing according to standards [45]. The cylinders are then cured in a lime bath in the humidity room at room temperature and 95% relative humidity until the day of testing. The compressive strength of concrete is usually measured by applying a uniaxial compression uniform load at a constant rate. The age of concrete at the time of testing depends on the type of application and it is normally at 1 day, 3 days, 7 days, 14 days, 28 days, and/or 90 days. However, the design compressive strength of concrete is usually based on the 28-day compressive strength.

The compressive strength of SCC is higher compared to conventional concrete (CC) having a similar w/c ratio. This effect may be related to improved quality of the interface between aggregate particles and the paste matrix in SCC mixtures [46]. Other researchers reported that SCC mixtures with a compressive strength as high as 80 Mpa (11,000 psi) can be easily achieved with low permeability, good freeze-thaw resistance and low drying shrinkage [47].

In SCC, replacing cement using Class F fly ash by up to 40%, 50% and 60% while keeping the cementitious material content constant at 400 Kg/m^3 have shown that showing that an economical SCC can be successfully developed by incorporating Class F fly ash. The achieved compressive strengths range from 26 to 48 MPa (4000 to 7000 psi). The water/cementitious material ratio range from 0.35 to 0.45 and the fine aggregate/coarse aggregate ratio was 50:50 [27].

3.7.2.2 Modulus of Elasticity

The modulus of elasticity is usually influenced more by the volume of aggregate and by the aggregate properties than by the paste properties. SCC mixtures usually have a lower aggregate content and larger paste volume compared to conventional concrete. Therefore, the modulus of elasticity of SCC is expected to be lower than that of conventional concrete having similar compressive strength [46]. Leemann and Hoffman [48] also reported that the modulus of elasticity of SCC averages a 16% lower than that of normally vibrated CC for identical compressive strengths. The modulus of elasticity of SCC is measured using the same test set-up used to measure that of conventional concrete [49].

3.7.2.3 Shrinkage

Shrinkage in concrete affects its strength as well as its durability and usually rely on the w/c ratio and the paste volume. Both ingredients are higher in SCC mixtures that in conventional concrete mixtures. Hence, it is important to evaluate shrinkage in SCC and minimize its effect. There are three types of shrinkages in cementitious materials based concrete, i.e. plastic shrinkage, autogenous shrinkage and drying shrinkage. The description of those types are as follows:

Plastic Shrinkage:

This type of shrinkage occurs during the early drying stages; shrinkage stress may develop on the surface layer of concrete because of water loss due to evaporation. If this water loss exceeds the bleeding of water from the concrete, a negative capillary pore develops between the particles. This capillary pressure causes plastic shrinkage that can cause cracking at the surface of the structure. The risk of plastic shrinkage cracking increases with reduced bleeding due to higher fine materials content [46].Therefore, SCC mixtures containing a large amount of filler material are more sensitive than normal weight concrete.

Autogenous Shrinkage:

Heat developed during the hydration process of cement and cementitious materials causes internal drying in the concrete, which leads to reduction in relative humidity. Consequently, tensile stresses develop, which may lead concrete shrinkage. This type of shrinkage is called autogenous shrinkage. The use of low w/c ratio or low water content due to the addition of pozzolanic material such as silica fumes can increase the risk of autogenous shrinkage in SCC.

Drying Shrinkage:

Drying shrinkage occurs when the relative humidity inside the concrete is very low and moisture dries out of concrete members at a high rate. This loss of absorbed water creates negative pore water pressure and causes changes in the microstructure of the concrete, leading to reversible and irreversible volume changes and eventually shrinkage stresses. Drying shrinkage occurs over a long period. Some of the factors which affect the drying shrinkage are paste content to aggregate content, the pore structure of the cement paste, water content and the elastic modulus of aggregate.

Self-consolidating concrete mixtures usually contain less aggregate and more paste than CC, hence drying shrinkage may be higher in SCC than in CC [46]. Other researcher reported that drying shrinkage of SCC is similar to that of CC [50]. Xie et al. [47] reported a drying shrinkage value of 383 x 10^{-6} mm/mm and SCC with ultra-pulverized fly ash has higher compressive strength, increased permeability and freezing resistance and lower drying shrinkage than that of conventional concrete.

CHAPTER 4: EXPERIMENTAL PROGRAM FOR SCC MIXTURES

4.1 INTRODUCTION

The fiber reinforced self-consolidating concrete (FRSCC) is a concrete mixture having the advantages of both SCC with the fibers to enhance and increase its post-cracking characteristics [5]. The use of FRSCC in interesting structural applications such as precast and pre-stressed elements, sheet piles, tunnel segments are listed within the literatures [21]. The addition of steel fibers and PVA fibers in concrete give rise to hybrid fibers, which improve the mechanical properties such as tensile strength, energy absorption, and most importantly, the tensile strain. The optimum amount of the fibers to be used in SCC should be selected to have the least effect on the workability while maintaining good flowability, passing ability and resistance to segregation [22]. On the other hand, the addition of SCMs aims to improve its durability properties, such as shrinkage, and permeability. Ibrahim et al. [2] conducted research on the feasibility of developing high-performance SCC with a high content of SCMs and researchers [5]–[7], [23] have conducted research on the development of hybrid fibers in SCC with partial replacement of cement with SCMs. However, few studies were found in the literature on replacing cement with a very high volume of SCMs *and* using hybrid fibers in SCC.

Ibrahim et al. [2] investigated the feasibility of developing ultra-strength high-performance SCC by replacing up to 70% of Portland cement by a combination of SCMs such as class C or class F fly-ash, granulated blast furnace slag, and silica fume. The investigation concluded that ultra-strength high-performance SCC could be developed with low water-cement ratio (w/cm) and up to 70% of cement replaced by SCMs having properties superior to those of the control mixtures made with 100% Portland cement. The four most promising SCC mixtures designed by Ibrahim et al. 2013 in terms of fresh properties: flowability, deformability, filling capacity and resistance to segregation, and compressive strength were selected for this investigation.

Hossain et al. [23] studied the influence of PVA, and hybrid fibers on the rheological properties of SCC using different concrete mixes, fiber types and partial replacement of Portland cement with furnace blast slag. Hossain et al. [23] recommends the optimum fiber combinations in terms of fresh properties − flowability, deformability, filling capacity and resistance to segregation − of 0.1% (0.083% of steel fiber and 0.017% nylon (PVA) fiber by volume), which is used to develop the first group of HFRSCC mixtures.

4.2 EXPERIMENTAL PROGRAM

A total of 12 concrete mixtures were designed and divided into three groups; the first group consisted of control mixtures made without fibers, and the second and third groups had 0.1% and 0.2% fiber combinations (by volume) of nylon (PVA) and steel fibers. The 0.1% fiber combination have 0.083% and 0.017% by volume of steel fiber and nylon (PVA) fiber, respectively and the 0.2% fiber combination have 0.166% and 0.034% by volume of steel fiber and nylon (PVA) fiber, respectively. These fiber combinations were used per the recommendation of Hossain et al. 2012 [23]. For each group, one mixture was prepared with 100% Portland cement; the remaining mixtures replaced with 70% of the Portland cement by a combination of high percentages of various SCMs. All concrete mixtures were designed based on typical SCC mixtures designed by Ibrahim et al. 2013 [2]. The dosages of superplasticizer were adjusted for each content of SCMs and fiber percentage to achieve an initial slump flow of 500 ± 10 to 750 ± 10 mm (20 to 30 in) and to satisfy the general requirements of HFRSCC (flowing ability, filling capacity, and resistance to segregation and bleeding). The water-to-cementitious materials ratio (w/cm) was kept constant at 0.45 and the coarse aggregate/total aggregate ratio (CAg/TAg) was kept constant at 0.5. The slump-flow and T_{50} test, the J-Ring test, and the segregation index test were used to evaluate the fresh properties of all the SCC mixtures. Furthermore, the mechanical properties such as compressive strength at 1, 7, 28, and 90 days, tensile strength at 28 days and 90 days (air cured after 28 days), modulus of elasticity at 28 days, and unrestrained shrinkage up to 91 days were also investigated. All the SCC mixtures were labeled numerically according to the group and mixture number. The group numbers represent the amount of fiber in the mixture. For example, GI represents the first group of control mixtures without fibers whereas GII and GIII represent the second and third group having 0.1 % and 0.2 % volume fractions of fiber combination of nylon (PVA) and steel fibers, respectively. Similarly, the mixture numbers represent the amount of cement and SCMs used in the mixture. For example, M1 represents the mixture with 100 % cement, M2 represents the mixture of 30 % cement (C) and 70%

ground granulated blast furnace slag (SL), M3 represents the mixture with 30% cement, 60% SL, and 10 % silica fume (SF), and M4 represents the mixture with 30% cement, 30% fly-ash (FA), 30% SL, and 10 % silica fume. Table 4.1 shows the proportions of the concrete mixture considered.

Table 4.1: Proportion of self-consolidating concrete mixtures

Group	Mixtures	Percentage of CM	Percentage of fiber		Cementitious Materials (lb/ft^3)[1]					Water		Aggregates			Superplasticizer (ml/ft^3)[2]
			Steel %	Nylon (PVA) %	CM	C	FA	SF	SL	W/CM	W (lb/ft^3)	FAg/TAg	FAg (lb/ft^3)	CAg (lb/ft^3)	
GI (0.0 %)	M1	100% C	0.00%	0.00%	28.09	28.09	0.00	0.00	0.00	0.45	12.64	0.5	54.62	54.62	67.34
	M2	30%C+70%SL			28.09	8.43	0.00	0.00	19.66	0.45	12.64	0.5	54.62	54.62	57.24
	M3	30%C+60%SL+10%SF			28.09	8.43	0.00	2.81	16.86	0.45	12.64	0.5	54.62	54.62	106.06
	M4	30%C+30%FA+30%SL+10%SF			28.09	8.43	8.43	2.81	8.43	0.45	12.64	0.5	54.62	54.62	64.81
GII (0.1 %)	M1	100% C	0.083%	0.017%	28.09	28.09	0.00	0.00	0.00	0.45	12.64	0.5	54.62	54.62	70.29
	M2	30%C+70%SL			28.09	8.43	0.00	0.00	19.66	0.45	12.64	0.5	54.62	54.62	71.55
	M3	30%C+60%SL+10%SF			28.09	8.43	0.00	2.81	16.86	0.45	12.64	0.5	54.62	54.62	104.38
	M4	30%C+30%FA+30%SL+10%SF			28.09	8.43	8.43	2.81	8.43	0.45	12.64	0.5	54.62	54.62	79.12
GIII (0.2 %)	M1	100% C	0.166%	0.034%	28.09	28.09	0.00	0.00	0.00	0.45	12.64	0.5	54.62	54.62	74.92
	M2	30%C+70%SL			28.09	8.43	0.00	0.00	19.66	0.45	12.64	0.5	54.62	54.62	88.38
	M3	30%C+60%SL+10%SF			28.09	8.43	0.00	2.81	16.86	0.45	12.64	0.5	54.62	54.62	112.79
	M4	30%C+30%FA+30%SL+10%SF			28.09	8.43	8.43	2.81	8.43	0.45	12.64	0.5	54.62	54.62	106.90

[1] 1 lb/ft^3 = 16.02 kg/m^3
[2] 1 ml/ft3 = 35.31 ml/m^3

4.3 MATERIALS

In the development of all SCC mixtures, a Type I Portland cement with a specific gravity of 3.15 and conforming to the requirements of the ASTM C150, "Standard Specification for Portland Cement" [51] was used. In all SCC mixtures, Type I cement along with a combination of one or more supplementary cementitious materials (SCMs) − ground granulated blast furnace slag (SL), fly-ash (FA) and silica fume (SF) − were used. The typical chemical composition of the cement and SCMs used are listed in

Table 4.2The detail results from Scanning Electron Microscopy / Energy Dispersive X-Ray Spectroscopy (SEM/EDS) analysis of the cementitious materials is appended in the Appendix-A. A well-graded crushed basalt with a minimum and maximum particle size of 5 and 19 mm (0.20 and 0.75 in), respectively was used as coarse aggregate. A well-graded silica sand was used as fine aggregate. Moisture absorption and specific gravity for coarse and fine aggregate were determined in accordance to ASTM C127, "Standard Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregate" [52] and ASTM C128, "Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate" [53], respectively. The relative specific gravity (SSD) and absorption of the coarse aggregate (CA) were 2.729 and 2.55%, respectively, whereas the fine aggregate (FA) had a relative specific gravity (SSD) of 2.683, absorption of 4.58%, and a fineness modulus of 2.93. The particle size distribution of fine and coarse aggregates with American Society for Testing and Materials (ASTM) lower and upper limits are shown in Figure 4.1. A high range water reducing and superplasticizing admixture (SP) utilizing Sika's 'ViscoCrete®' polycarboxylate polymer technology confirming the requirements for ASTM C 494 Types A and F was also used in the SCC mixtures. The technical specifications of the superplasticizer (SP) could be found in Appendix-B. The specific gravity of SP was 1.08 and was blue liquid in appearance. This type of SP was formulated to provide extreme workability and prevent segregation to concrete due to which VMA was not added. The recommended dosages are between 325-780 mL/100kg (5-12 fl oz/100 lbs) of cementitious materials. The steel fiber and nylon fiber were provided by Sika Corporation. Figure 4.2 shows the steel and nylon (PVA) fibers used in the mixtures. The properties of the steel and nylon (PVA) fibers used in the

HFRSCC are listed in Table 4.3. The aggregates were kept in dry condition and were clean and free of any organic materials.

Table 4.2: Typical chemical characteristics of cement and cementitious materials

Components	Type I Cement	Fly Ash	GGBF Slag	Silica Fume
C K	0.0	41.3	10.4	0.0
O K	55.6	34.1	38.7	47.2
F K	0.0	0.0	0.8	0.5
Na K	0.4	1.3	0.1	0.2
Mg K	0.4	1.3	2.4	5.6
Al K	1.9	3.5	5.5	10.4
Si K	6.7	7.1	12.6	33.1
S K	1.7	0.4	0.8	0.0
K K	0.3	0.5	0.2	0.5
Ca K	31.1	7.9	27.8	0.6
Ti K	0.1	0.4	0.4	0.0
Fe K	1.7	2.2	0.0	2.0
Mn K	0.0	0.0	0.2	0.0

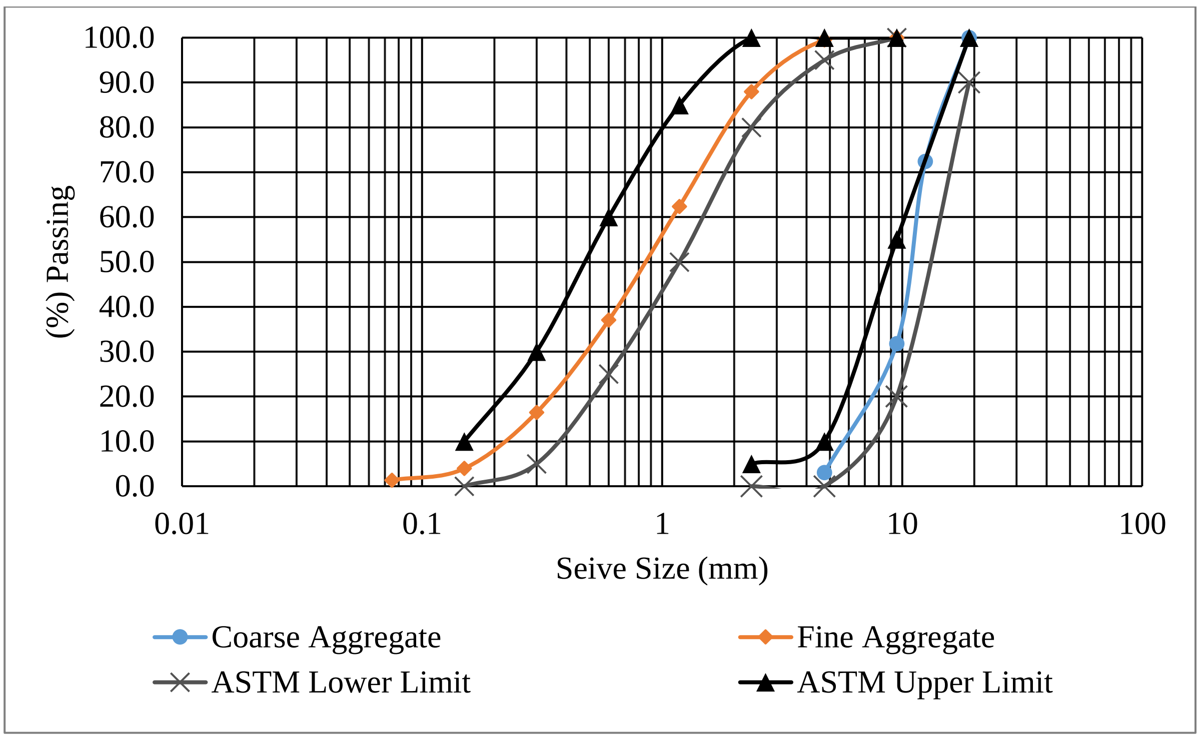


Figure 4.1: Particle size distribution of fine and coarse aggregates

4.4 PREPARATION OF SAMPLES AND MIXING TECHNIQUE FOR SCC

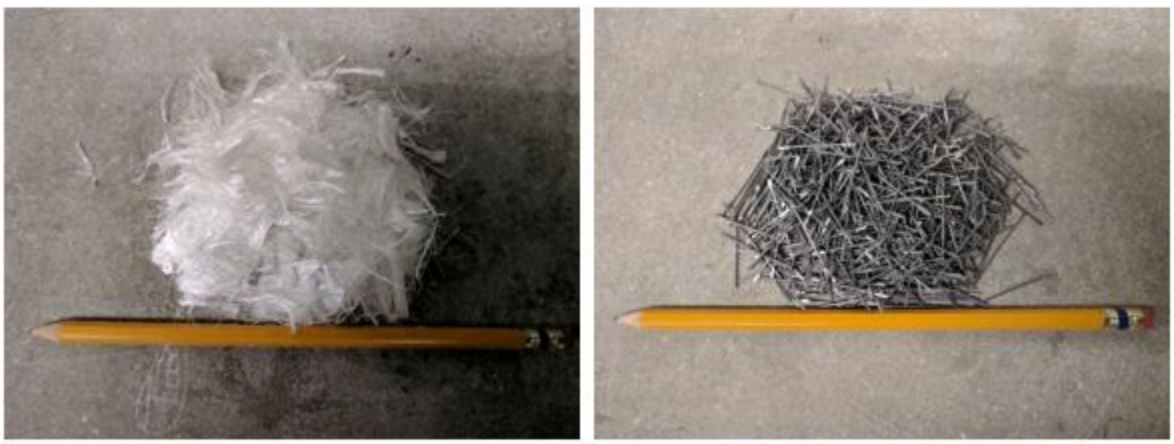
A rotatory drum mixer was used to mix all concrete ingredients in accordance with the ASTM C 192 “Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory” [54]. First, the coarse and fine aggregates were added to the rotating mixer and mixed for 30 seconds and the aggregates were brought to Saturated Surface Dry (SSD) conditions by adding a small amount of water. After the SSD aggregates were mixed for another 30 seconds, the cement and other SCMs were added to the mixer and continued to mix for another 30 seconds. Next, 60 % of the water was poured over the mix, and the mixing continued for another 30 seconds. The SP was added to the remaining water which was added to the mix and allowed to mix for another 60 seconds. The steel fibers followed by nylon (PVA) fibers were then added to the mixer after stopping for 30 seconds in order to prevent from fibers from clumping together. Then the mixing was continued until the homogenous mixture was produced. Generally, the total time for mixing ranged from 10 to 15 minutes. The fresh properties were measured immediately after mixing. To ensure mixture homogeneity, mixing was resumed for the intervals between the two subsequent tests (slump flow with and without the J-Ring).

From each concrete mixture, a total of eight 100 x 200 mm (4 x 8 in) concrete cylinders and two 150 x 300 mm (6 x 12 in) concrete cylinders were prepared. These eight cylinders were used to measure the compressive strength at 1, 7, 28, and 90 days and the two were used to measure the tensile strength and modulus of elasticity of concrete, respectively. Concrete cylinders prepared from SCC mixtures were not rodded or vibrated at the time of casting. All prepared concrete cylinders were covered and left in plastic molds undisturbed for 24 hours. Subsequently, they were unmolded and stored in 95% or higher humidity until the day of testing. All the moist-cured samples were tested within one hour after removal from curing room. Figure 4.3 shows concrete samples being cured in the curing room. An additional two 50 x 50 x 250 mm (2 x 2 x10 in) concrete prisms were also prepared from each concrete mixture in accordance with ASTM C490 “Standard Practice for Use of Apparatus for The Determination of Length Change of Hardened Cement Paste, Mortar and Concrete” [55]. They were cast, covered, and kept undisturbed in the curing room for 24 hours. After unmolding, both specimens were kept in the curing room at 95% or higher humidity for 7 days followed by air curing at room temperature. Figure 4.3 also shows mortar prisms being cured in the curing room.

Table 4.3: Fiber Properties

Steel Fiber	Material	Length	Diameter	Aspect Ratio (L/D)	Tensile Strength (MPa)	Deformation
SikaFiber® Force XR	Steel	38 mm (1.5")	1.14 mm (0.045")	34	966-1242 MPa (140-180 Ksi)	Continuously deformed circular segment

Nylon Fiber	Material	Color	Specific Gravity	Length	Melt Point	Water Absorption	Acid Resistance	Alkali Resistance
SikaFiber® FN	Monofilament nylon	White	1.16	19 mm (0.75")	260°-265°C (490°-510°F)	Less than 5%	High	High



(a) (b)

Figure 4.2: (a) Nylon (PVA) Fiber (SikaFiber® FN) (b) Steel Fiber (SikaFiber® Force XR)

4.5 STANDARD TESTS AND TESTING PROCEDURES FOR SCC

The tests are performed in three stages; testing for fresh properties, mechanical properties testing and durability testing. First, the fresh properties of concrete mixtures were evaluated to ensure that the concrete is self-consolidating concrete. Then, the mechanical properties (the compressive strength, the tensile strength, and modulus of elasticity) of all prepared concrete mixtures were evaluated. Finally, the durability of all concrete mixtures was assessed by measuring the unrestrained shrinkage. The brief description of the test performed in this study are presented in the following sections.

Figure 4.3: Concrete being cured in the curing room and in water tank

4.5.1 Fresh Properties Evaluation of SCC Mixtures

4.5.1.1 Slump Flow, and T_{50} Tests

The flowability and the rate of deformability of all self-consolidating concrete mixtures were measured by the slump flow and T_{50} tests. An inverted slump cone is used to measure the slump flow and the test is performed as per ASTM C 1611, "Standard Test Method for Slump Flow of Self-Consolidating Concrete" [56]. The cone mold has a top and bottom diameter of 100 mm (4 in) and 200 mm (8 in), respectively and a height of 300 mm (12 in). The inverted cone is filled with concrete and lifted vertically. The SCC does not require any rodding or vibration. Then, the spread of the concrete patty along the two perpendicular diameters of the concrete spread was measured after a full stop and considered as the slump flow value. The T_{50} test was used to assess the rate of concrete deformability in which the time for concrete spread to reach a 500 mm (20 in) diameter was measured during the slump flow test. In general, a slump flow value between 500 and 750 mm (20 and 30 in) and a value of T_{50} varying between 2 and 7 seconds are considered acceptable for SCC design [3]. A typical setup for slump flow and T_{50} tests are shown in Figure 4.4.

(a) (b)

Figure 4.4: (a) Slump flow test set-up, (b) measuring slump flow of SCC mixtures

4.5.1.2 Segregation Tests

Segregation in SCC mixture can be of concern due to its high flowability and if not dealt with proper care, significant segregation can be seen during the sampling. The results thus obtained could be misleading. So, all concrete samples were handled in similar manner with proper care and strict quality control. To assess the segregation resistance i.e. the stability of the mixtures, segregation index test was used.. The test consists of visually inspecting the concrete patty after lifting the slump cone in the slump flow test. Visual inspection focuses on the accumulation of coarse aggregate particles in the center of the concrete patty and the flow of free water around its perimeter [44].

The segregation resistance of the SCC mixture is determined based on the assigned segregation index (SI). The criteria to assign the SI value is explained in the appendix of ASTM C 1611, "Standard Test Method for Slump Flow of Self-Consolidating Concrete" [56]. It states that if there is no obvious accumulation of coarse aggregate particles in the center of the concrete patty and no free water flowing around its parameter, the segregation index is equal to zero (SI = 0), and the SCC mixture is assumed to have a full resistance to segregation i.e. highly stable mix. If the SCC mixture exhibited an apparent accumulation of coarse aggregate particles in the center of the patty or small amount of water flowing around the parameter, the segregation index is equal to one (SI = 1), and the concrete mixture is unlikely to segregate, hence stable. In the case of obvious accumulation of coarse aggregate particles or free water, the segregation index is equal to two (SI = 2), and the SCC is likely to segregate.

Finally, a large amount of accumulated coarse aggregate particles or a large amount of free water flowing indicates that the concrete will segregate and the mixture will be rejected. Figure 4.4b shows a typical SCC patty with an SI = 0.

4.5.1.3 J-Ring Test

To measure the passing ability of the concrete through obstacles the J-Ring test was performed for all SCC mixtures in accordance with ASTM C 1621, "Standard Test Method for Passing Ability of Self-Consolidating Concrete by J-Ring" [57]. Similar to the slump flow test, the J-Ring test consists of measuring the average diameter of the concrete spread after lifting the inverted concrete cone and the time needed for the concrete to reach a circle of a 500 mm (20 in) diameter but inside the J-ring (a ring attached to steel rods 100 mm (4 in) apart as obstacles). To perform the test, the inverted slump cone was placed concentrically in the J-ring and filled with freshly mixed concrete without rodding or vibration. The cone was then raised vertically and the concrete is allowed to spread under its own weight, passing through the steel bars. The ring was then removed and the mean diameter of the spread is recorded. The time needed for the concrete spread to reach a circle of 500 mm (20 in) diameter was also recorded as the T_{50} value with the J-Ring. As per EFNARC 2005, for SCC mixtures to have an acceptable passing ability, the difference in slump flow value measured using the J-Ring and without J-Ring should not be more than 100 mm (4 in). The difference between the T_{50} values measured using the J-Ring test and the slump flow test are recommended to be more than 2 to 4 seconds for SCC made without any kind of fibers. The Figure 4.5 shows the J-ring test set-up and a typical concrete spread using the J-Ring.

4.5.2 Mechanical Properties of SCC Mixtures

4.5.2.1 Compressive Strength Test

The compressive strength of all SCC mixtures was determined using a 100 x 200 mm (4 x 8 in) concrete cylinders at 1, 7, 28, and 90 days. The average compressive strength of two cylinders was taken as the compressive strength of that mixture. The sample preparation and test was done as per ASTM C39, "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens" [45]. All cylinders were moist cured in the curing room at room temperature and at 95% or higher humidity until the day of testing. Cylinders were removed from the curing room and excess moisture on the surface was wiped off. Cylinders were then capped using neoprene caps and tested using a compression machine with 2224 kN (500 kip) capacity. During testing, the load was applied continuously and without shock at a loading rate of 250 ± 50 kPa/s (35 ± 7 psi/sec) until failure. Compressive strength was calculated as a quotient of the maximum load attained during the test by the surface area of the specimen, based on the average diameter measurement. Figure 4.6 shows the compressive strength test set-up and a typical failure mode of a concrete cylinder.

(a) (b)

Figure 4.5: (a) J-Ring test setup (b) Typical concrete spread using the J-Ring test

Figure 4.6: Compressive strength test set-up and a typical failure mode of a concrete cylinder under axial compression

4.5.2.2 Modulus of Elasticity Test

The modulus of elasticity of all the concrete mixtures was determined using a 150 x 300 mm (6 x 12 in) concrete cylinder at 28 days. The test was performed in accordance with ASTM C469, "Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concert in Compression" [49]. For this test, concrete cylinders were cured in the curing room at room temperature and 95% or higher humidity until the day of testing. Cylinders were removed from the curing and excess water from the surface was wiped off using cloth rags. The cylinder was then set-up with the Compressometer and was leveled. Cylinders were then capped using Neoprene caps. The load was applied at a constant rate of 241 ± 34 kPa/s (35 ± 5 psi/sec). The applied load and longitudinal strain were recorded without interruption at the following two points; (1) when the longitudinal strain was 50 millionths and (2) when the applied load was equal to 40% of the ultimate load. The specimen was loaded at least twice in addition to a first loading for the seating of the gages. The results are taken from the average of two subsequent loadings. The modulus of elasticity of the concrete was calculated using the following equation.

$$E = \frac{(S_2 - S_1)}{(\in_2 - 0.000050)}$$

Where, E = chord modulus of elasticity, S_2 = stress corresponding to 40% of ultimate load, S_1 = stress corresponding to a longitudinal strain ($\in_1$) of 50 millionths, and $\in_2$ = longitudinal strain produced by stress S_2,

Figure 4.7 shows the modulus of elasticity test set-up and the test.

Figure 4.7: Modulus of elasticity test set-up

4.5.2.3 Indirect Tensile Strength Test

The splitting tensile strength of all concrete mixtures was determined using a 150 x 300 mm (6 x 12 in) concrete cylinder at 28 days and 91 days (28 days moist cured followed by air curing). The sample preparation and test was done as per ASTM C 496, “Standard Test for Splitting Tensile Strength of Cylindrical Concrete Specimens” [58]. For this test, concrete cylinders were all cured in the curing room at room temperature and 95 % or higher humidity until the day of testing. Cylinders were removed from the curing room and excess moisture on the surface was wiped off. The cylinders were marked, measured and placed longitudinally on the loading machine similar to the compression test. A plywood strip at the top and bottom of the specimen was placed along the center of the lower bearing block of the loading machine and the specimen. Then, a supplementary bearing plate was placed on top of the plywood strip and centered on the line marked on the specimen and the thrust of the spherical block. The load was applied continuously and without shock at a loading rate of 700 to 1400 kPa/min (100 to 200 psi/min) splitting tensile strength until failure. The tensile strength of concrete was calculated using the following equation.

$$T = \frac{2P}{\pi LD}$$

Where, T = splitting tensile strength, psi, P = maximum applied load, lbs, L and D = length, and diameter of the concrete specimen, in.

Figure 4.8 shows the splitting tensile strength test set-up and a typical failure mode of a concrete cylinder using the splitting tensile test.

(a) (b)

Figure 4.8: (a) Splitting tensile strength test set-up and (b) Typical failure mode of a concrete cylinder under tension.

4.5.3 Durability Property of SCC Mixtures

4.5.3.1 Unrestrained Shrinkage Test

The unrestrained (free) shrinkage for all concrete mixtures was measured using the digital comparator test set-up as shown in Figure 4.9. The test consists of a sturdy upright support with a digital indicator gauge mounted on the top and a reference bar. The digital indicator has a range of 12.7 mm (0.5 in) and 0.00127 mm (0.00005 in) divisions. The unrestrained shrinkage of all concrete mixtures was measured using 5 x 5 x 25 cm (2 x 2 x 10 in) concrete prisms. From each concrete mixture, two concrete prisms were prepared as previously described. Both mold prisms were covered with wet towels left undisturbed for 24 hours. They were then unmolded and placed in the curing room at room temperature and 95% or higher humidity for 15 minutes and the initial 24-hour reading was taken. Then they were continuously moist cured for 7 days followed by air curing at normal room temperature.

The change in length for prisms was measured in accordance with ASTM C 490, “Standard Practice for Use of Apparatus for The Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete” [55]. The change in length for each prism was recorded after 7 days of casting and once a week thereafter for 91 days. Figure 4.9 shows the Comparator test set-up and a concrete specimen being tested.

Figure 4.9: Unrestrained shrinkage test set-up and a concrete prism being tested

CHAPTER 5: RESULTS AND DISCUSSIONS FOR SCC MIXTURES

5.1 INTRODUCTION

This research aims at developing hybrid fiber reinforced self-consolidating concrete (HFRSCC) made with a very high volume of supplementary cementitious materials (SCMs). For that, a total of 12 concrete mixtures were designed and divided into three groups; the first group is control mixtures made without fibers, and the second and third groups had a 0.1% and 0.2% fiber combinations (by volume) of nylon (PVA) and steel fibers. For each group, one mixture is prepared with 100% Portland cement and remaining mixtures were prepared with 70% of Portland cement replaced by a combination of high percentages of various SCMs. The SCC properties examined are the compressive strength at 1, 7, 28, and 90 days, the tensile strength at 28 days and 90 days, the modulus of elasticity at 28 days, and the unrestrained (free) shrinkage up to 91 days and were explained in Chapter 3. The control mixtures were designed to be self-consolidating and to achieve acceptable flowability and deformability, and adequate resistance to segregation. The fresh properties of the control and fiber mixed SCC were measured using slump flow and T_{50} tests with and without J-Ring and the segregation index test to ensure the self-consolidating properties of the mixes. All the mixtures fresh properties are presented in Table 5.1.

5.2 FRESH PROPERTIES OF SCC MIXTURES

Current standards for self-consolidating concrete [3], [4] recommended certain requirements to classify concrete as SCC. It states that the common value of slump flow for SCC is in between 450 mm and 760 mm (18 in and 30 in) and the T_{50} values between 2 and 5 seconds. This requirement is to ensure lateral flowability, deformability and filling ability of the SCC mixtures. Another requirement is to maintain the maximum difference between the slump flow values with and without the J-Ring and the T_{50} values with and without the J-Ring less than 50 to 100 mm (2 to 4 inches) and 1 to 3 seconds, respectively. It is needed to ensure the ability of the SCC mixtures to flow through reinforcement congestion under its own weight and consolidate itself without the need of mechanical vibration. Finally, the Visual Stability Index (VSI) test is used to ensure the stability of SCC mixtures. SCC mixtures must exhibit high resistance to segregation due to the high flowability of SCC mixtures which causes a problem in stability during mixing, placing, and setting.

Table 5.1 shows that the slump values for all SCC mixtures measured in this study and as shown the values lie between 550 and 650 mm (22 and 26 inches) indicating that all mixtures met the flowability requirement. The T_{50} values without the J-Ring in Table 5.1 are between 2 to 7 seconds, which shows less deformability. In addition, Table 5.1 also shows the slump flow and T_{50} value with the J-Ring for all SCC mixtures. It shows that although it was feasible to develop high viscosity concrete, such concrete exhibits very low deformability as it is indicated by the high T_{50} values of the mixtures. The low deformability is due to the fact that the HRWRA used in this study contains a viscosity-modifying agent in its production and using high dosages of such admixture to achieve a slump flow value higher than 20 in (500 mm) enhances concrete viscosity as well. However, the main reason for high viscosity of mixtures is the dense particle packing and the hybrid fiber content which led to low deformability of concrete. This behavior was also observed visually while performing the slump flow test, in which, concrete took a longer time to reach a full stop. Since all SCMs used are of lower specific gravity than cement, they always increased the paste volumes. The SCMs enhanced the fresh properties (flowability, deformability, and the passing ability) of concrete and the increase in the paste volume further increased the enhancement. The author did try to measure the slump flow with and without the J-Ring multiple times in every batch by adjusting the HRWRA in each time. Those trials attempted to reach the specified values of the T_{50}. Very limited and almost no standards could be used to specify the optimum amount of the HRWRA that can give the exact time to spread between 550 and 650 mm (22 and 26 inches). Figure 5.1 and Figure 5.2 shows that the comparison between the slump flow and T_{50} test with and without J-Ring, respectively. The results of the fresh properties indicate that it is feasible to produce a very comparable SCC with a hybrid fibers and with high volume of SCMs. Finally, most SCC mixtures in this study showed a high resistance to segregation and bleeding with all segregation indexes equal to zero except one value between 0 and 1 as shown in Table 5.1.

Table 5.1: Properties of fresh SCC mixtures

Group	Mixtures		Slump Flow without J-Ring (in.)[3]	Slump Flow with J-Ring (in.)	T_{50} without J-Ring (Sec.)	T_{50} with J-Ring (Sec.)	Segregation Index (SI)
GI (0.0%)	M1	100% C	22.50	21.75	7.00	10.00	0
	M2	30%C+70%SL	24.50	19.00	5.89	12.00	0
	M3	30%C+60%SL+10%SF	24.50	22.00	5.44	7.09	0
	M4	30%C+30%FA+30%SL+10%SF	24.00	23.25	5.20	5.50	0
GII (0.1%)	M1	100% C	25.25	24.75	5.64	7.23	0
	M2	30%C+70%SL	24.75	22.50	5.59	9.74	0
	M3	30%C+60%SL+10%SF	23.50	20.50	5.60	8.23	0
	M4	30%C+30%FA+30%SL+10%SF	22.25	19.00	3.65	6.95	0
GIII (0.2%)	M1	100% C	24.75	19.75	4.30	9.30	0
	M2	30%C+70%SL	24.75	20.75	2.80	3.90	0-1
	M3	30%C+60%SL+10%SF	24.00	22.50	4.00	4.52	0
	M4	30%C+30%FA+30%SL+10%SF	24.00	20.25	2.10	4.67	0

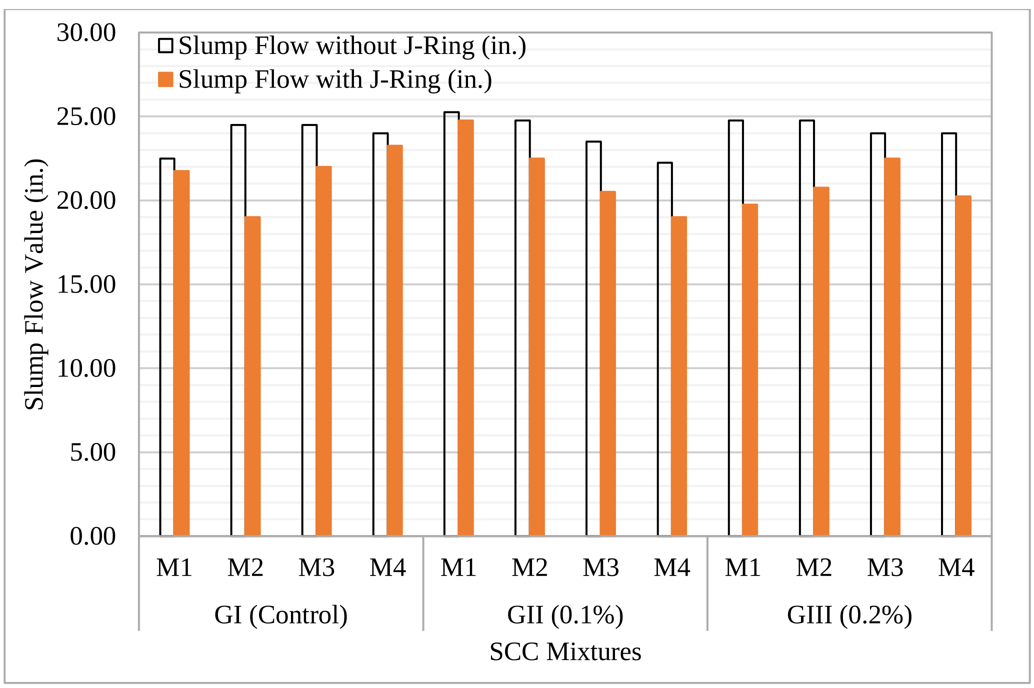


Figure 5.1: Slump flow values for all SCC mixtures with and without the J-Ring

[3] 1 in = 25.4 mm

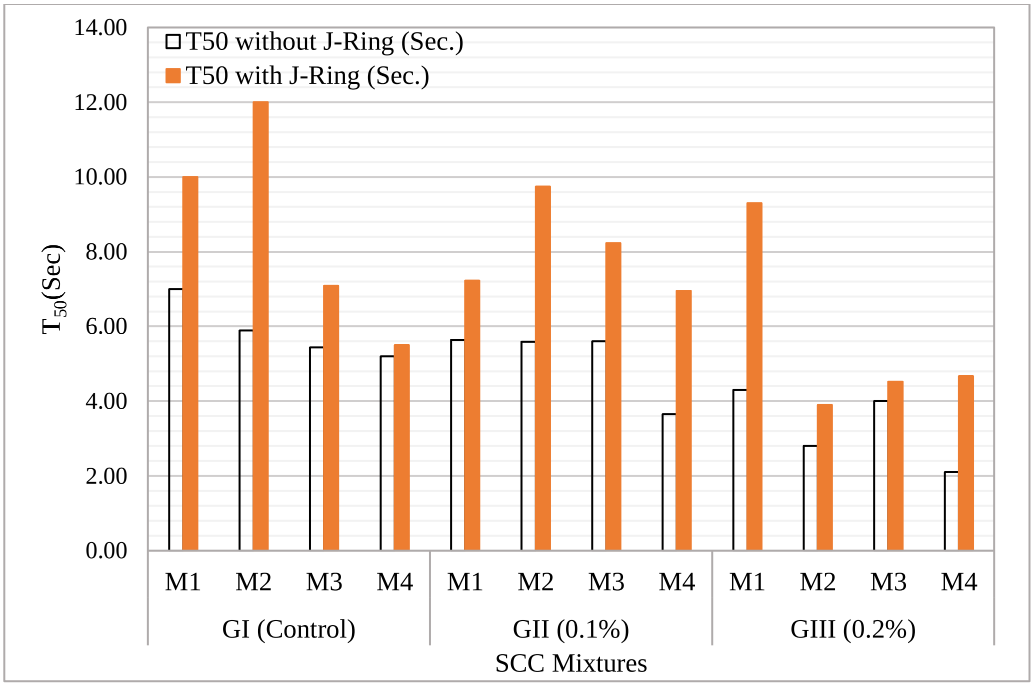


Figure 5.2: T_{50} values for all SCC mixtures with and without the J-Ring

5.2.1 Effect of Hybrid Fiber and High Content of SCM on the Fresh Properties of HFRSCC

The effects of hybrid fibers and a high content of supplementary cementitious materials (SCMs) on the fresh properties of the hybrid fiber reinforced self-consolidating concrete (HFRSCC) observed from the above data are listed below.

1) As expected, the addition of fibers increases the amount of superplasticizer required to maintain the self-consolidating properties of all mixtures. The increase was up to 25 % when 0.1% fiber was introduced and was up to 65 % for mixtures contained 0.2% fiber.
2) The least effect of fiber inclusion was seen in the mixture containing 30% cement, 60% Slag and 10% Silica fume. The increase was 7 % on average in the amount of superplasticizer for mixtures made with 0.1% and 0.2% fiber.
3) The highest effect of fiber inclusion was seen in the mix M4 (30%C+30%FA+30%SL+10%SF), where the increase in the amount of superplasticizer required was 22% and 65% for 0.1% and 0.2% fiber, respectively.
4) Replacing cement with slag and fly-ash increased the workability and deformability as mixtures required less or almost equal amounts of SP to achieve the SCC properties

compared to M1 (100 % cement mixture). By contrast, the silica fume decreased the workability and deformability of the mixtures resulting in the higher amount of SP used to achieve the SCC properties.

5) The effect of fiber and the high content of SCMs on the stability of SCC mixtures can be determined from the segregation index values listed in Table 5.1. It is difficult to draw a solid conclusion on the effect of fiber and the high content of SCMs on the stability as all mixes had a segregation index value of either 0 or between 0 and 1. However, while investigating the fresh properties in the lab, we were able to observe visually that silica fume enhanced the stability of concrete by reducing segregation and bleeding whereas slag and fly-ash have limited or had no effect on the stability.

5.3 MECHANICAL PROPERTIES OF HFRSCC MIXTURES

The compressive strength, tensile strength, and modulus of elasticity are considered the most important mechanical properties of concrete and they were investigated for all concrete mixtures considered. The compressive strength was measured at different ages (i.e. 1, 7, 28, and 90 days) to determine the early and long-term effect of hybrid fibers with the high content of SCMs on the mechanical and durability properties. The tensile strength, however, was only measured at 28-days and 90 days (moist-cured for 28 days followed by air curing) to determine the relationship between the compressive and the tensile strength of the proposed concrete and to compare to conventional concrete. Results of the compressive, tensile strength and modulus of elasticity are shown in Table 5.2.

5.3.1 The Effect of Hybrid Fiber and High Content of SCM on the Compressive Strength of HFRSCC

The results from the compressive strength test at 1, 7, 28 and 90 days are presented in Table 5.2 and the Figure 5.3. Figure 5.4 shows the comparison of the compressive strength of all the SCC mixtures.

Table 5.2: Mechanical properties of all concrete mixtures

Mechanical Properties									
Group	**Mixture**		***f'c*** **(psi)[4] 1 day**	***f'c*** **(psi) 7 days**	***f'c*** **(psi) 28 days**	***f'c*** **(psi) 90 days**	***ft*** **(psi) 28 days**	***ft*** **(psi) 90 days**	***E*** **(psi) 28 days**
GI (0.0%)	M1	100% C	3695	7623	8751	9916	621	791	2.20E+06
	M2	30%C+70%SL	539	3924	5654	7526	480	599	1.99E+06
	M3	30%C+60%SL+10%SF	785	4568	6943	7787	437	566	2.19E+06
	M4	30%C+30%FA+30%SL+10 %SF	350	2066	4063	5366	344	451	1.61E+06
GII (0.1%)	M1	100% C	3838	7429	8970	10030	545	774	2.27E+06
	M2	30%C+70%SL	598	4030	5947	7491	439	523	2.04E+06
	M3	30%C+60%SL+10%SF	497	3468	4564	6492	391	478	1.58E+06
	M4	30%C+30%FA+30%SL+10 %SF	410	2145	3770	5843	365	414	1.60E+06
GIII (0.2%)	M1	100% C	2932	6000	7775	8718	578	629	1.92E+06
	M2	30%C+70%SL	396	2988	4936	6800	428	531	1.63E+06
	M3	30%C+60%SL+10%SF	779	3247	4320	6677	409	463	1.45E+06
	M4	30%C+30%FA+30%SL+10 %SF	655	2608	4652	6551	457	459	1.57E+06

5.3.1.1 Effect of percentage of fibers considering the amount of SCMs

The effects of the percentage of fibers on the compressive strength considering the amount of SCMs are constant and are listed below.

1) The mixture that contains 0.1% volume fraction of fibers (GII-M1) showed higher compressive strength than the control mixture (GI-M1), while the compressive strength of mixture made with 0.2% fibers (GIII-M1) decreased by 12% compared to (GII-M1).
2) Mixtures made with 70% slag and 0.1% fibers (GII-M2) had the same compressive strength as the control mixture (G1-M2) while increasing the percentage of fibers to 0.2% decreased the compressive strength by 10% compared to the control mixtures (GI-M2).
3) Replacing the cement by 60%SL+10%SF with 0.1% and 0.2% fibers decreased the compressive strength on average by 15% compared to the control mixture (GI-M3).

[4] 1 psi = 6.895 kPa

4) The compressive strength of mixtures made with quaternary blends (30%C+30%FA+30%SL+10%SF), showed an overall increase in compressive strength by 9% and 22% for the 0.1 and 0.2% fiber volume fractions.
5) It is concluded that the quaternary blend mixtures (M4 group) showed an overall increase in the compressive strength. However, all mixtures showed a compressive strength at 28 days greater than the average specified compressive strength (4450 psi) for structural concrete mixtures being used in the six highway districts in Idaho. The mixtures investigated in this study could be used in many different applications across the state significantly reducing carbon emissions due to the very high percentage of cement replacement by SCMs.

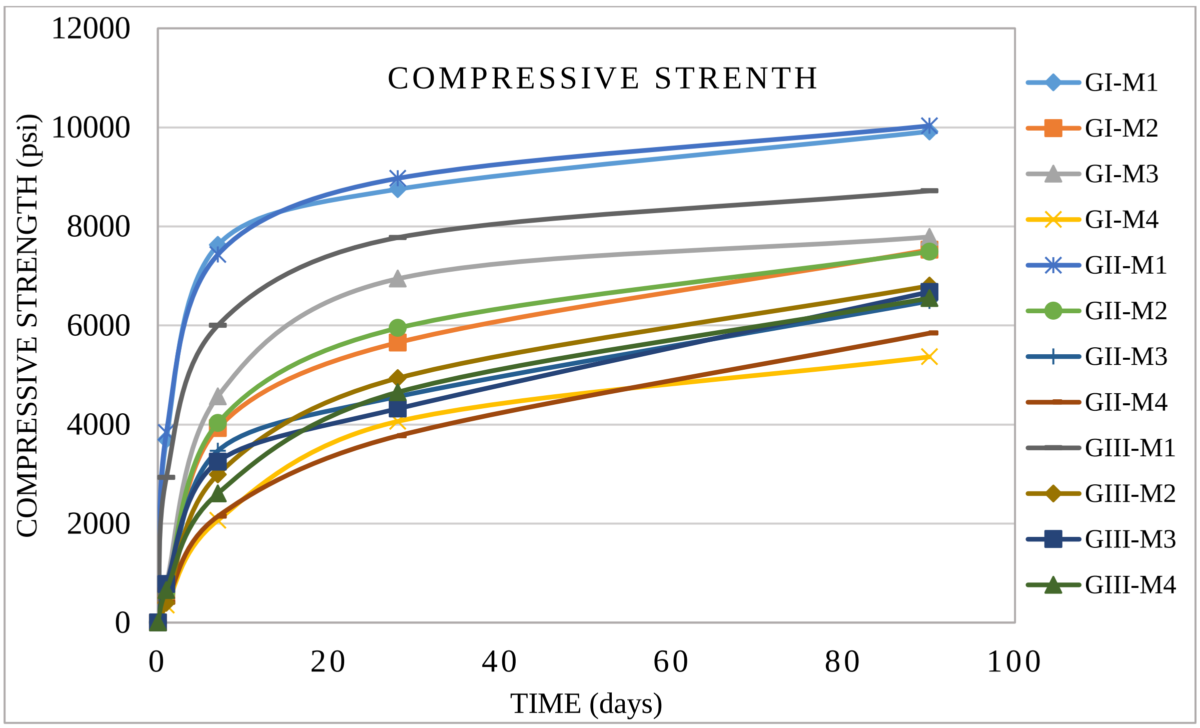


Figure 5.3: Compressive strength of all the SCC mixtures

5.3.1.2 Effect of different percentages of SCMs

The effect of different percentage of SCMs on the compressive strength of the concrete is listed below.

1) The compressive strength of control mixtures in GI group (with no fibers) and with 100% cement showed some important results. The replacement of cement with

30%FA+30%SL+10%SF showed a significant decrease in the compressive strength (30.5% compared to the control mixture GI-M1), and that might be attributed to the high w/c ratio.

2) It is known that adding steel fibers to concrete increases compressive strength, however, that was not the case for the mixtures tested in this study. In group GII where a hybrid fiber percentage of 0.1% was added to the mixture, the compressive strength decreased significantly by an average of 22.6% compared to the control mixture GII-M1. For example, the mixtures contain 70% slag had a compressive strength of 7,491 psi compared to 10,030 psi at 90-days for GII-M1.
3) The third group GIII has a hybrid mixture of fibers with a volume fraction of 0.2%, the compressive strength for GIII decreased by an average of 23% for all three mixtures compared to the control mixture GIII-M1.
4) The highest compressive strength of 10,030 psi at 90-days was achieved from mixture GII-M1, whereas the lowest compressive strength of 5,366 psi of mixture G1-M4.

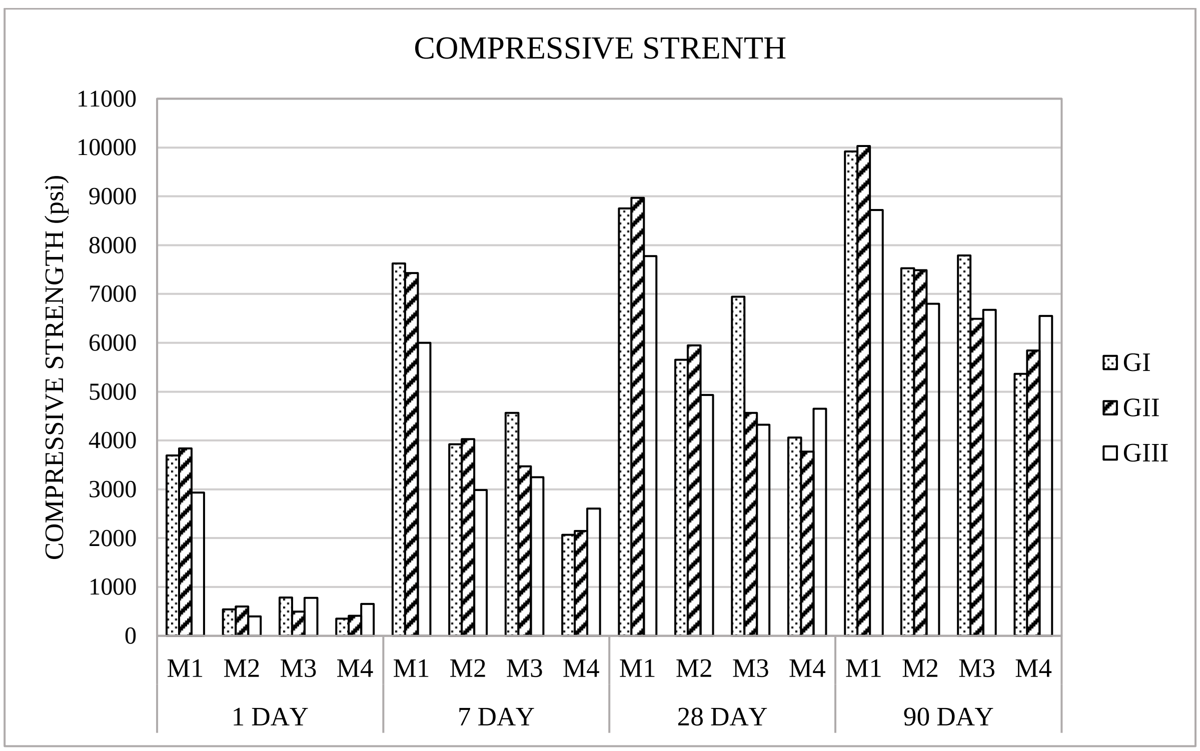


Figure 5.4: Comparison of Compressive strength of all the SCC mixtures

5.3.1.3 Effect of Superplasticizer (SP)

The relationship between the amount of superplasticizer and the compressive strength is shown in Figure 5.5 and as expected, increasing the amount of SP, decreases the compressive strength.

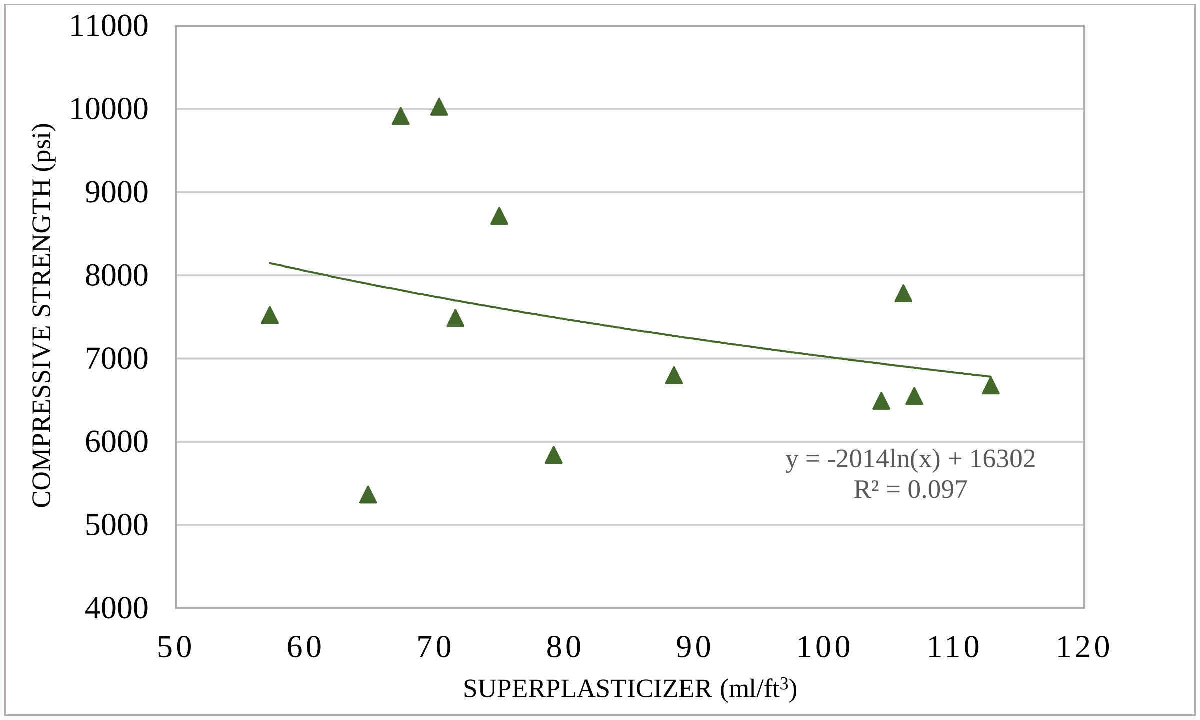


Figure 5.5: Effect of Superplasticizer on compressive strength of all the SCC mixtures

5.3.2 The Effect of Hybrid Fiber and High Content of SCM on the Tensile Strength of HFRSCC

The effects of hybrid fiber and the high content of SCMs on the tensile strength of HRFSCC are listed below.

1) The relationship between the amount of superplasticizer and the tensile strength is shown in Figure 5.6. As expected, increasing the amount of SP decreases the tensile strength.
2) Overall, the tensile strength decreased with adding the 0.1% and the 0.2% fibers to all concrete mixtures, which can be seen in Figure 5.7 and Figure 5.8. The highest tensile strength obtained at the age of 28 days was 621 psi of the control G1-M1 mixtures, whereas the lowest value of 344 psi was observed from mixture G1-M4, which has the corresponding lowest compressive strength.

3) The three control mixtures in all groups had a tensile strength at the age of 28 days of 621, 545, 578 psi for mixtures without fibers, with 0.1%, and 0.2%, respectively.
4) Mixtures made with 70% slag combined with 0.1% and 0.2% fibers showed a 10% decrease in tensile strength compared to the control mixture G1-M2, which matches with the same percent decrease (10%) in compressive strength.
5) Replacing the cement by 60%SL+10%SF with 0.1% and 0.2% fibers decreased the tensile strength on average by 8.5 % compared to the control mixture (GI-M3).
6) The tensile strength of mixtures with quaternary blends (30%C +30%FA +30%SL +10%SF), showed an overall increase in tensile strength of 5% and 23% for the 0.1 and 0.2% fiber volume fractions.

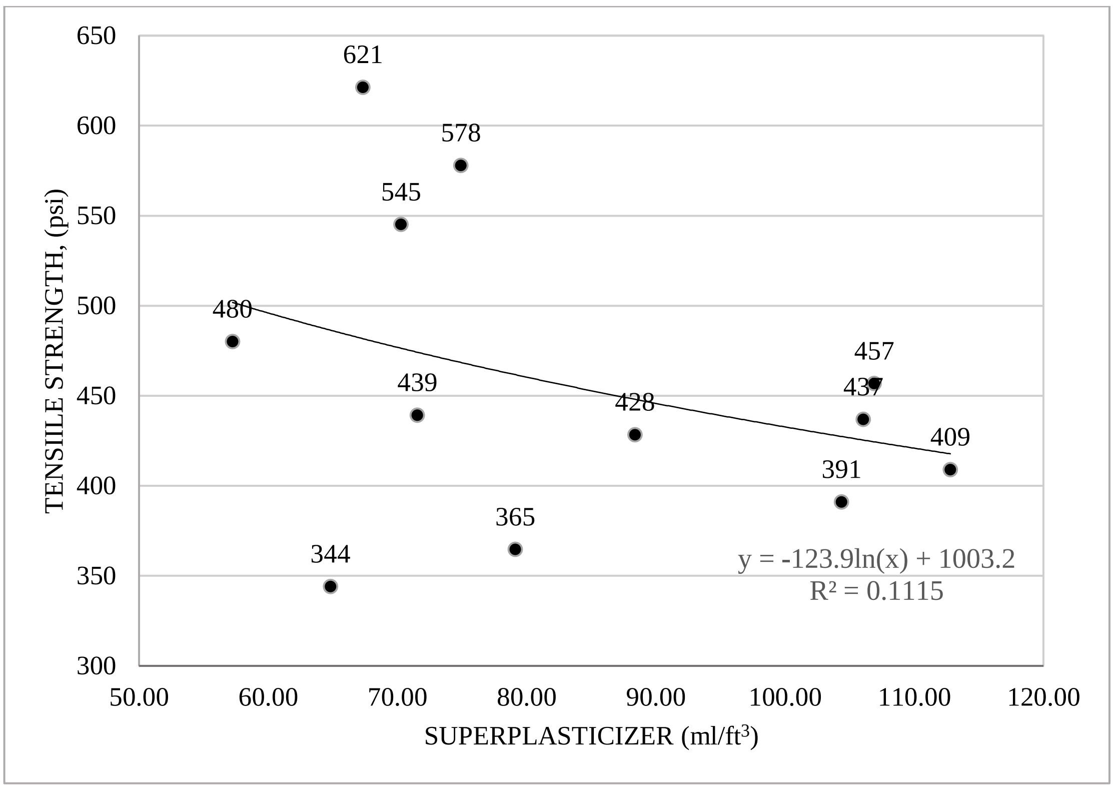


Figure 5.6: Effect of Superplasticizer on tensile strength of all the SCC mixtures

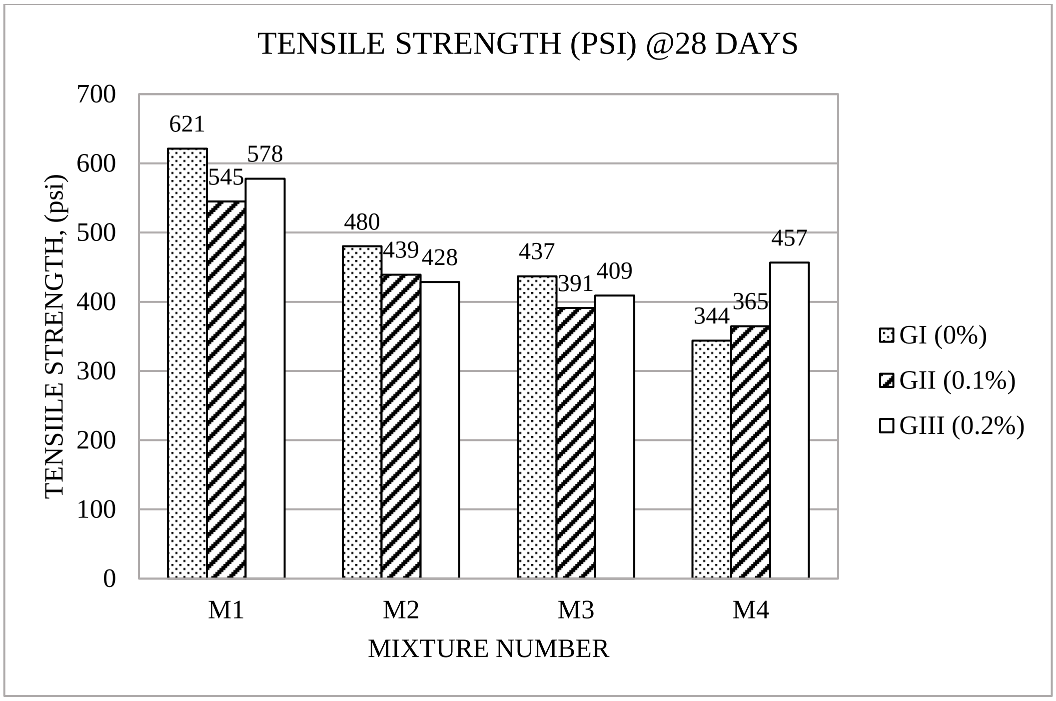


Figure 5.7: Comparison of tensile strength at the age of 28 days of all the SCC mixtures

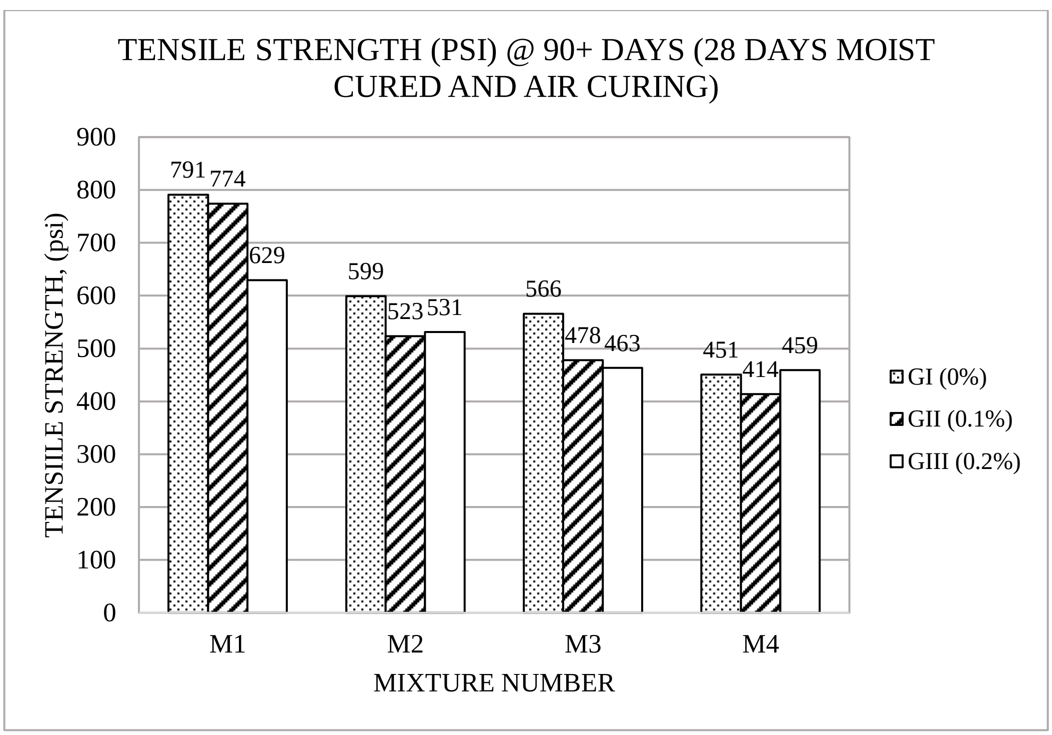


Figure 5.8: Comparison of tensile strength at the age of 90 days (28 days moist cured followed by air curing) of all the SCC mixtures

5.3.3 The Effect of Hybrid Fiber and High Content of SCM on the Modulus of Elasticity of HFRSCC

1) The modulus of elasticity results are shown in Table 5.2 and Figure 5.9. The results show that the modulus of elasticity decreases significantly for 0.2 % fiber content. For the 0.1 % fiber content, mixtures M1 and M2 show an increase in modulus of elasticity whereas mixture M3 had a decrease in modulus of elasticity and mixture M4 had no change.
2) The relationship between the amount of superplasticizer and the modulus of elasticity is shown in Figure 5.10 and as expected, overall increasing the amount of SP, decreases the modulus of elasticity.
3) ACI Committee 237 2007 [4] provided a relationship between the compressive strength and modulus of elasticity and proposed that the modulus of elasticity is proportional to the square root of the compressive strength. Figure 5.11 shows a relationship between the compressive and modulus of elasticity of all SCC mixtures considered in this study. It is clear that the relationship provided by ACI Committee 237 2007 is not valid for HFRSCC mixtures made with high content of SCMs especially when these mixtures developed high compressive strength. A new relationship is proposed which assumes that the modulus of elasticity of HFRSCC is proportional to its compressive strength to the power of 0.475 instead of 0.5 as shown in Figure 5.11. The new equation better represents the relationship between the modulus of elasticity *(E)* in psi and compressive strength *(f'_c)* in psi of HFRSCC as follows:

$$Modulus\ of\ Elasticity\ (E) = 30000 * {f_c'}^{0.475}$$

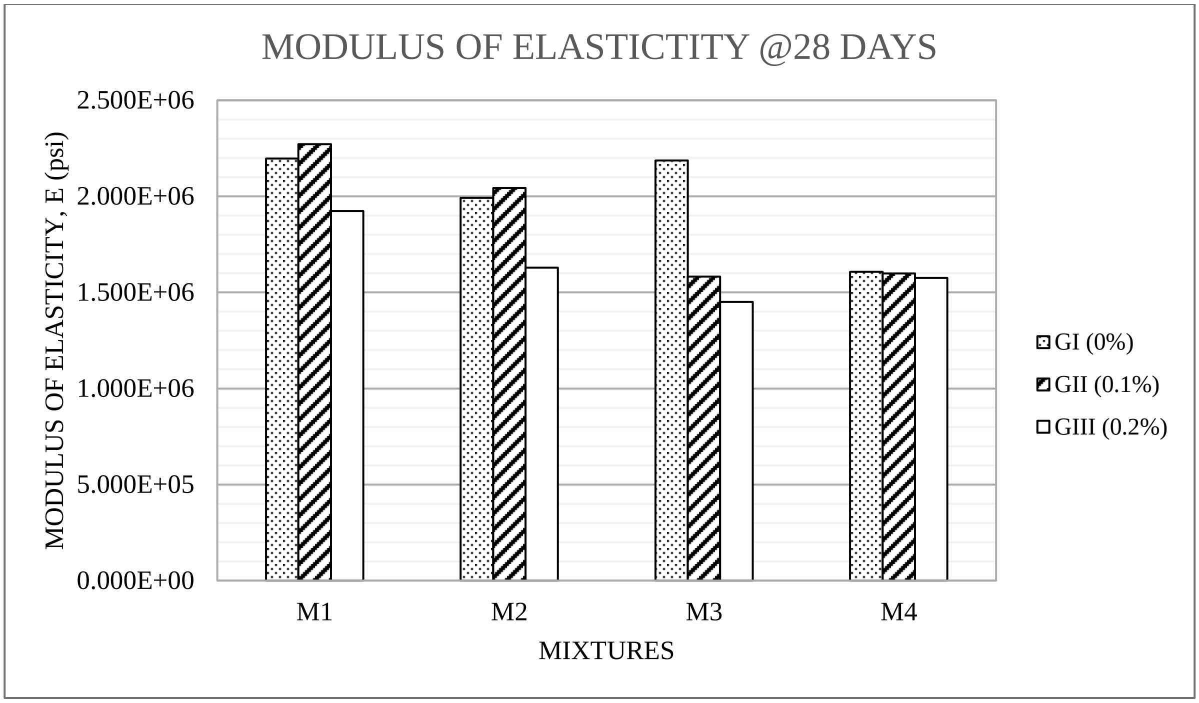


Figure 5.9: Comparison of Modulus of Elasticity at the age of 28 days of all the SCC mixtures

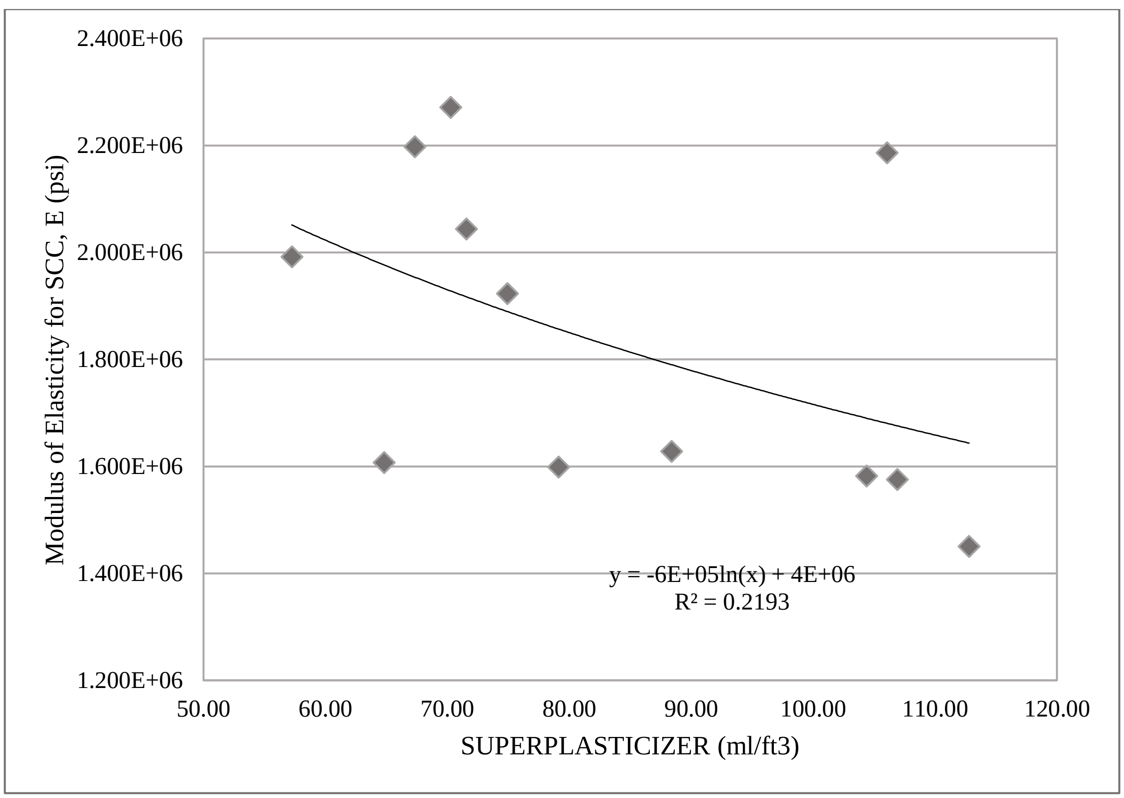


Figure 5.10: Effect of Superplasticizer on Modulus of Elasticity of all the SCC mixtures

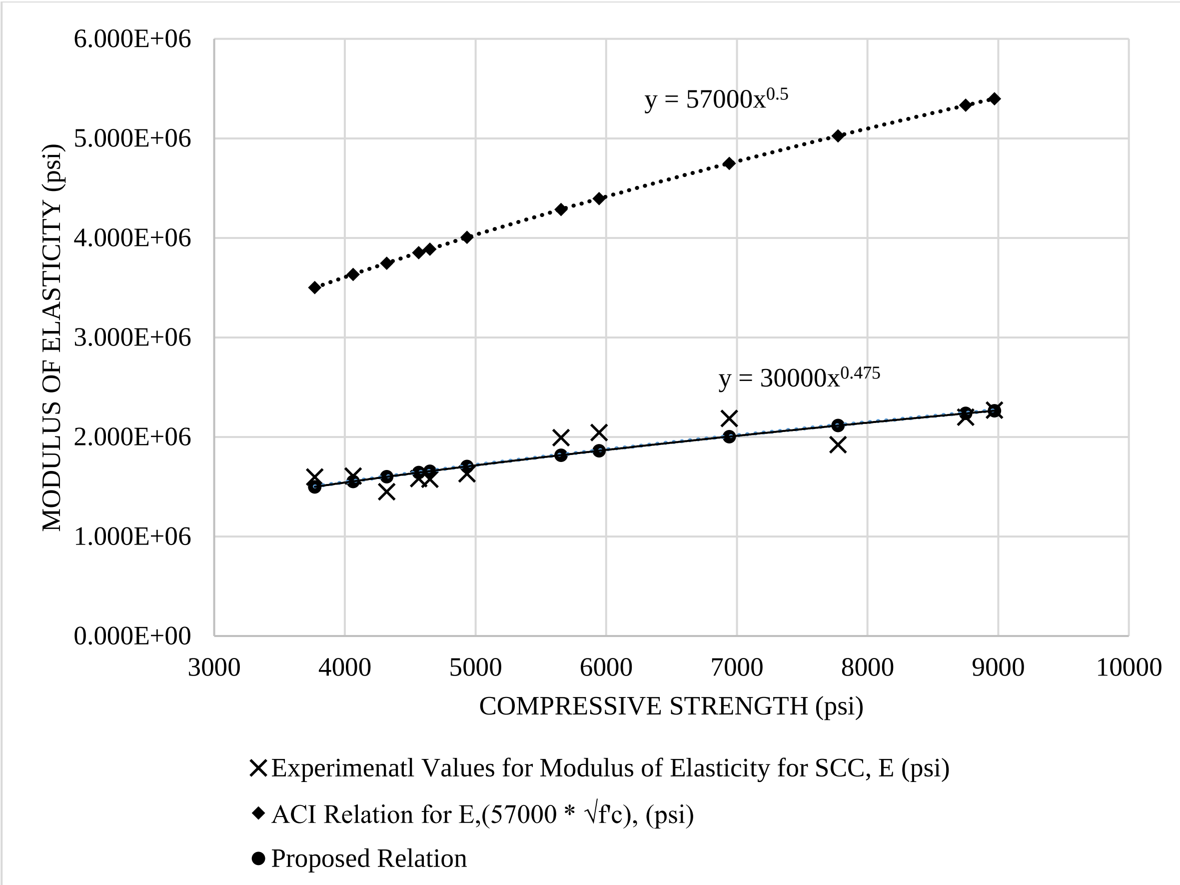


Figure 5.11: Relationship between the compressive strength and the modulus of elasticity of Hybrid fiber reinforced Self-Consolidating Concrete mixtures made with high content of Supplementary Cementitious Material

5.4 FREE SHRINKAGE OF THE SCC MIXTURES

The unrestrained shrinkage of all concrete mixtures investigated in this study was measured using the comparator test set-up explained in Chapter 3. The free shrinkage was measured using 50 x 50 x 250 mm (2 x 2 x 10 in) concrete prisms prepared from each mixture and cured in the curing room with 95% or higher relative humidity for 7 days followed by curing at room temperature in the open air. The free shrinkage results for all the SCC mixtures are shown in Figure 5.12.

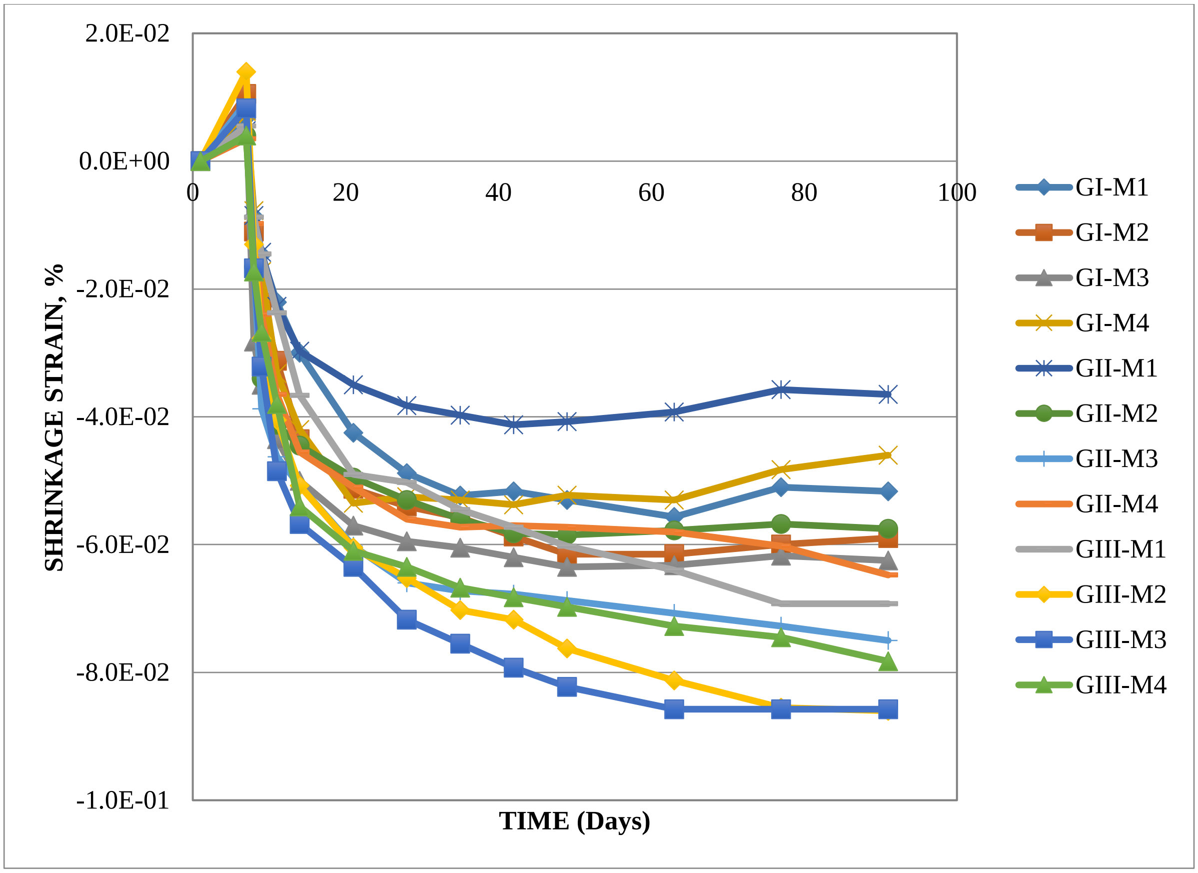


Figure 5.12: Free shrinkage of all the SCC mixtures

5.4.1 The Effect of Hybrid Fiber and High Content of SCM on the free shrinkage of HFRSCC

All mixtures showed expansion in the first 28 days and then started to shrink, with the amount of shrinkage strain depending on the mixture constituents.

5.4.1.1 Effect of percentage of fibers considering the high amount of SCMs

The effect of percentage of fibers is constant. All the SCC mixtures have increased ultimate shrinkage (microstrain) with the inclusion of fiber except for the 0.1 % fiber and 100 % cement mix (GII-M1), which shows a decrease in the ultimate shrinkage strain, as shown in Figure 5.13.

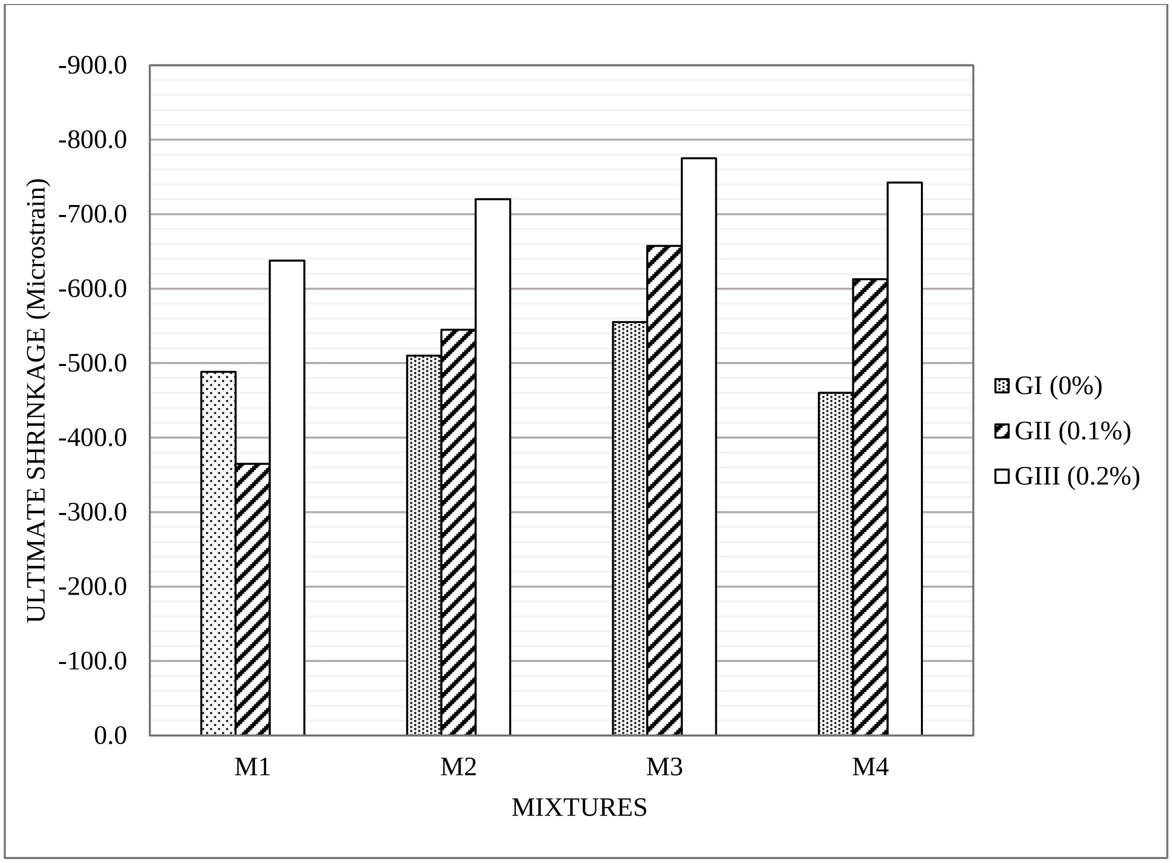


Figure 5.13: Effect of fibers on Ultimate free shrinkage (microstrain) of all the SCC mixtures

5.4.1.2 Effect of different percentages of SCMs

The effects of the different percentage of SCMs on the free shrinkage of the concrete are listed below.

1) The effect of different percentage of SCMs is shown in Figure 5.14. For the first group with 0% fiber the ultimate shrinkage increases as we replace the cement with SCMs for M2 (30% cement and 70% slag) and M3 (30% cement, 60% slag and 10% silica fume) whereas for M4 (30% cement, 30% fly-ash, 30% slag, 10 % silica fume) it decreases significantly.
2) For the remaining group (0.1% fiber and 0.2 % fiber) replacing cement by high content (70%) of SCMs increases the unrestrained ultimate shrinkage up to 61% as compared to the control mix. The reason is the high w/c ratio used in this study. Using a high percentage of SCMs increased the volume of the cement paste which consequently increased the ultimate shrinkage strain.

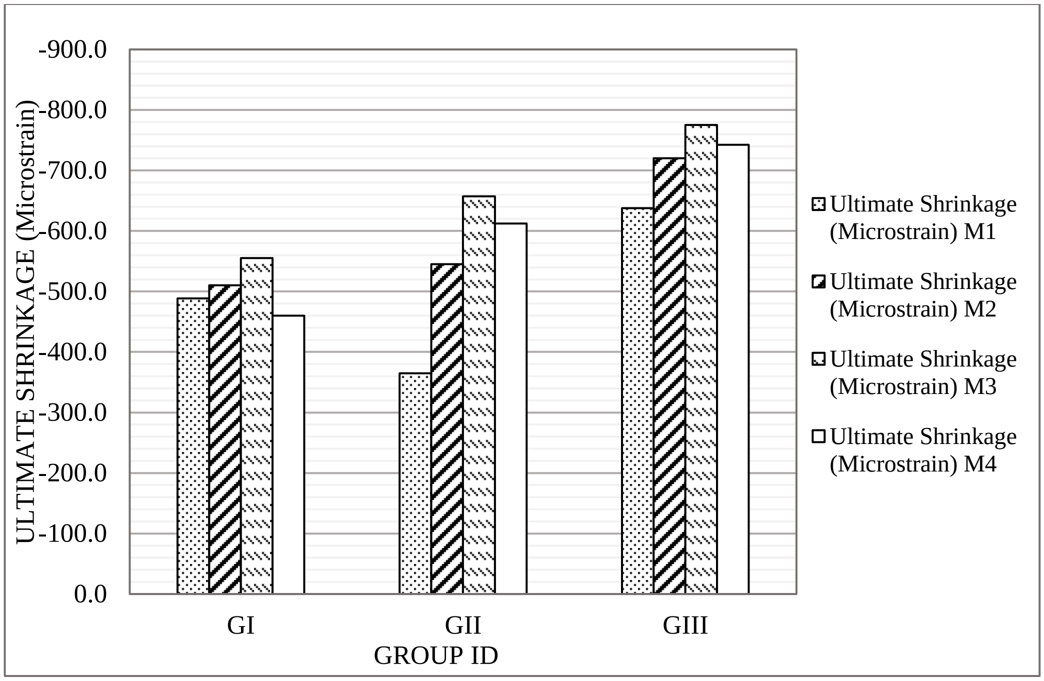


Figure 5.14: Effect of SCMs on the Ultimate shrinkage (micro strain) of all the SCC mixtures

5.4.1.3 Effect of Superplasticizer (SP)

The relationship between the amount of superplasticizer and the ultimate free shrinkage is shown in Figure 4.15 and as expected, overall increasing the amount of SP, increases the ultimate free shrinkage.

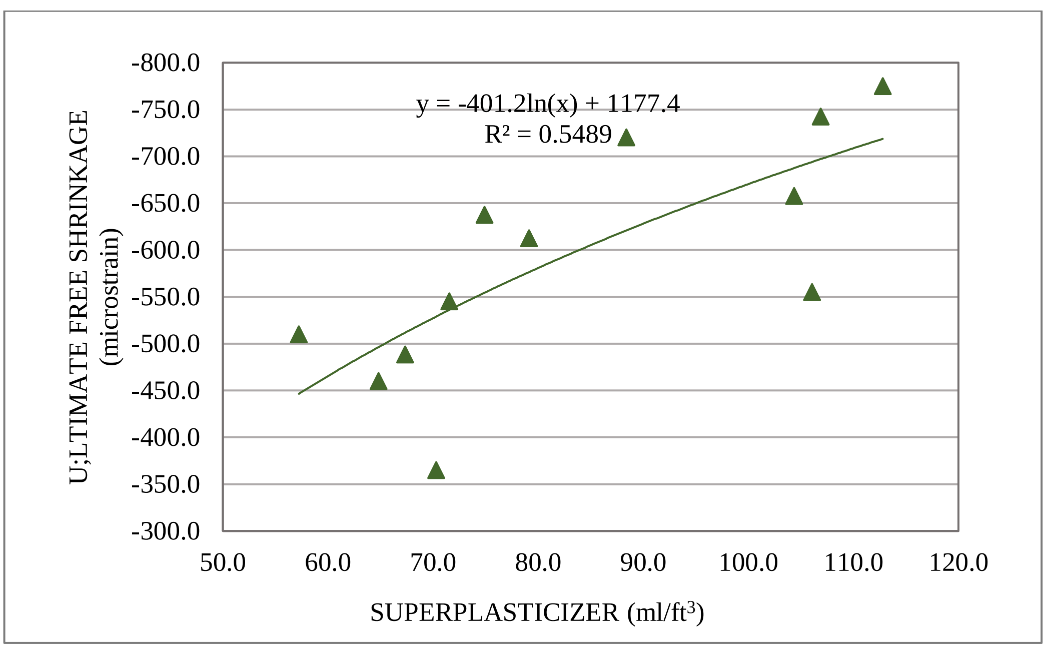


Figure 5.15: Effect of Superplasticizer on ultimate free shrinkage (microstrain) of all the SCC mixtures

CHAPTER 6: SUMMARY AND CONCLUSIONS FOR SCC MIXTURES

6.1 FRESH PROPERTIES OF HFRSCC

All the SCC mixtures met the flowability requirement per ASTM and had resistance to segregation and bleeding but the mixtures containing fibers showed less deformability in its fresh state. It was feasible to develop high viscosity HFRSCC, however such concrete exhibited very low deformability. The low deformability is due to the high dosages of superplasticizer (HRWRA containing VMA) which enhance the viscosity by dense particle packing resulting in low deformability.

The amount of superplasticizer needed to produce self-consolidating concrete increased with the addition of fibers. Replacing the cement with slag and fly-ash increased the workability and deformability of the mixtures whereas silica fume had opposite effect. The effect of fibers and a high content of SCMs on stability were not quantifiable but visually the silica fume enhances the stability while slag and fly ash had limited or no effect on stability.

6.2 MECHANICAL PROPERTIES OF HFRSCC

For the mixture with 100% cement, adding 0.1% fiber increased the compressive strength whereas the compressive strength decreases when the fiber content is increased to 0.2%. The mixture with 70% slag and 0.1% fiber have similar compressive strength as the control mixture i.e. without fibers but there is a decrease in compressive strength when using 0.2% fibers. The mixture M3 (30% C+60% SL+10%SF) showed a decrease in compressive strength when fibers were added. All the mixtures have an average 28-day compressive strength greater than the average specified compressive strength (4450 psi) for structural concrete mixtures being used in the six districts of the State of Idaho. Using such concrete will help in carbon emission reduction due to very high percentage of cement replacement.

The quaternary blend mixture showed a significant decrease in compressive strength compared to the 100 % cement mixture. Overall, the addition of hybrid fibers to concrete should show increased compressive strength; however, that was not the case for the mixtures tested in this study. This might be attributed to the amount of superplasticizer used to achieve the SCC properties. As the fiber percentage increased the amount of superplasticizer required to achieve the SCC properties increased significantly for all the mixtures.

The addition of fibers has a similar effect on the tensile strength of the mixtures as compressive strength. Overall, the tensile strength decreased with the addition of 0.1% fiber and 0.2% fibers. Again, the decrease in the tensile strength might be due to the large amount of SP required for SCC when there are fibers in the mixtures.

The modulus of elasticity decreased for the 0.2% fiber volume fraction whereas for the 0.1% fiber content no trend was seen in the modulus of elasticity. The relationship between the compressive strength and modulus of elasticity of all the SCC mixtures considered in this study is not similar to the conventional concrete as purposed by ACI Committee 237 2007 [4]. Hence, a new relationship is proposed for the relationship between compressive strength and modulus of elasticity for the HFRSCC mixtures with the modulus of elasticity being proportional to compressive strength to the power of 0.475 for the SCC mixtures.

6.3 DRYING SHRINKAGE OF HFRSCC

Overall, the ultimate drying shrinkage (microstrain) increased with the addition of fibers. The SCC mixtures with no fibers and binary and ternary blends have increased ultimate shrinkage compared to the control mixture whereas for the quaternary blend the ultimate shrinkage decreases significantly. However, SCC mixtures with 0.1% fiber and 0.2% fiber made with SCMs have greater ultimate drying shrinkage. The reason for is as follows. The mixes in this study have a high w/c ratio to begin with. Increasing the percentage of SCMs increases the volume of the cement paste which consequently increases the ultimate shrinkage strain. Also, the addition of fibers increases the amount of SP required to achieve the SCC properties which also increases the ultimate drying shrinkage.

6.4 GENERAL CONCLUSIONS FOR HFRSCC

This research provides the results from an experimental study investigating the feasibility to develop a hybrid fiber reinforced self-consolidating concrete with 70% of the Portland cement replaced by Supplementary Cementitious Materials (SCMs). The following observations and conclusion can be drawn from the results of this investigation.

1. It is feasible to produce a SCC with hybrid fibers and with high volume of SCMs. The mixtures developed in this study showed a compressive strength at 28 days greater than the average specified compressive strength (4450 psi) for structural concrete mixtures used in the six highway districts of the state of Idaho.
2. Using HFRSCC with high a content of SCMs will not only help lower the production cost of the concrete but also reduce the lifecycle cost of concrete structures, reduce CO_2 emission due to cement production, preserve natural resources used as raw materials for cement, and reduce the amount of industrial by-product wastes to be dumped in landfills.

6.5 RECOMMENDATIONS FOR FUTURE RESEARCHES FOR HFRSCC

1. Investigate other durability issues such as freeze-thaw, chloride attack, other acid attacks, and carbonation for HFRSCC mixtures made with high content of SCMs.
2. Research on long-term performance of HFRSCC.
3. The performance of HFRSCC mixtures in different weather conditions (Hot and Cold).
4. Investigation on more % of fiber and higher content of SCMs.
5. Investigating the effect of Superplasticizer on HFRSCC and preparing a standard guideline for the use of superplasticizer on HFRSCC.

CHAPTER 7: PORTLAND CEMENT CONCRETE MATERIAL CHARACTERIZATION FOR AASHTOWARE PAVEMENT ME DESIGN IMPLEMENTATION IN IDAHO

7.1 BACKGROUND

State Departments of Transportation (DOT)'s and highway agencies are making the transition from American Association of State Highway and Transportation Officials (AASHTO) 1993 Design Guide to the newly developed AASHTOWare Pavement Mechanistic Empirical (ME) Design. Over the past few years, Idaho Transportation Department (ITD) has actively initiated the basic preparation work needed to implement the ME design software to design flexible pavements. To date, ITD has developed a material database and training modules and implementation manual that enable the design engineer to design flexible pavement. However, ITD has not yet started similar steps for the design of rigid concrete pavements. Hence, this chapter presents preliminary results to start to implement the ME software for PCC pavement design.

Pavement ME represents a contemporary design guide for new and rehabilitated pavement structures, based on mechanistic and empirical principles. Pavement agencies are required to undertake the initial steps to transition from AASHTO 1993 design to Pavement ME. One of these steps is the establishment of a database with material properties of locally used paving materials. The primary goal of the Portland cement concrete material characterization for Pavement ME design implementation in Idaho is the development of a concrete material database for Pavement ME, to represent the most typical paving concrete mixtures from Idaho. The concrete materials for typical concrete mixtures from four districts of Idaho were collected. All the concrete mixtures were mixed at Washington State University (WSU) and then the specimens were moved to the material laboratory at the University of Idaho (UI) to conduct various test as described in the following sections. All the mixture design data sheets are presented in Appendix C.

7.2 MATERIALS

The following section describes a review of the materials requirements based on ITD materials manual. Samples from each of the four ITD districts (six mixtures) were collected with their sources of aggregate. All cement and fly ash samples are considered representatives from Lafarge and Ash Grove as shown in Appendix C.

7.2.1 Requirements for Aggregate

The coarse and fine aggregate used for concrete paving should conform to the requirements specified in ITD's Specification Book, Section 703.02 [59]. Per the specification, aggregate should be free from wood, roots, debris, soft or disintegrated particles and detrimental material in general. The aggregate's Alkali-Silica Reactivity (ASR) should be examined by the procedures outlined in AASHTO T 303, ASTM C 1293 or ASTM C 295 and mitigation measures, such as fly ash or lithium admixtures may be implemented in the case of high reactivity. Fine aggregate for concrete should meet the gradation requirements provided in Table 7.1.

Table 7.1: Fine aggregate gradation requirements, as specified by ITD Spec. Book (Table 703.02-3).

Sieve Size	**Percent Passing**
3/8 in.	100
No. 4	95~100
No. 16	45~80
No. 50	10~30
No. 100	3~10
No. 200	0~4[5]

The sand equivalent of the fine aggregate is determined by the AASHTO T 176 procedure and the minimum requirement for the sand equivalent is seventy. The content of organic impurities must satisfy the criteria define by the AASHTO T 21, while the content of deleterious substances, determined by AASHTO M 6, must be less than one percent by mass for clay lumps, coal and lignite, and less than five percent by mass for all other types of

[5] *The amount of the material passing sieve No. 200 is limited to 0~2 percent for concrete wearing surfaces (pavements, approach slabs, bridge decks).

particles. Recycled concrete fine aggregate must not be used. Coarse aggregate for concrete should meet the gradation requirements provided in Table 7.2.

Table 7.2: Coarse aggregate gradation requirements as specified by ITD Spec. Book (Table 703.02-6).

	1	**2a**	**2b**	**3**	**4**	**5**
Sieve Size	**Percent Passing**					
2 1⁄2 in.						100
2 in.					100	95~100
1 1⁄2 in				100	95~100	
1 in.		100	100	95~100		35~70
3⁄4 in.	100	90~100	80~100		35~70	
1⁄2 in.	90~100			25~60		10~30
3/8 in.	40~70	20~55	10~40		10~30	
No. 4	0~15	0~10	0~4	0~10	0~5	0~5
No. 8	0~5	0~5		0~5		

Per the ITD specification, the coarse aggregate must demonstrate less than 35 percent mass loss on Los Angeles Abrasion Test (AASHTO T 96). Deleterious substances content, determined by the AASHTO M 80, must be less than one percent by mass for coal and fine material (passing the sieve No. 200), less than 0.5 percent by mass for the clay lumps, and less than 2 percent by mass for clay lumps with friable particles. The requirements for the combined gradation of coarse and fine aggregate are provided in Table 7.3.

7.2.2 Requirements for Portland Cement Concrete

Concrete basic mixture design parameters should conform to the requirements given in Table 7.4 and Table 7.5.

Table 7.3: Combined aggregate gradation requirements as specified by ITD Spec. Book (Table 703.02-8)

Aggregate Size Number	1C	2C	3C	4C	5C
Sieve Size	**Percent Passing**				
2 1⁄2 in.				0	
2 in.				0	0~5
1 1⁄2 in		0	0~5	5~15	
3⁄4 in.		0	0~5	5~15	8~18
1⁄2 in.	0	0~5	5~15	8~18	8~18
3/8 in.	5~18	8~18	8~18	8~18	8~18
No. 4	8~20	8~18	8~18	8~18	8~18
No. 8	8~20	8~18	8~18	8~18	8~18
No. 16	8~20	8~18	8~18	8~18	8~18
No. 30	8~20	8~18	8~18	8~18	8~18
No. 50	8~20	8~18	8~18	8~18	8~18
No. 100	5~18	5~15	5~15	5~15	5~15
No. 200	0~4	0~4	0~4	0~4	0~4
Pan	0~2	0~2	0~2	0~2	0~2

Table 7.4: Concrete basic mixture design requirements as specified by ITD Spec. Book (Table 703.02-8)

Concrete Class in (psi) (28-day)	Min. Cement Content (lb/yd^3)	Max. Water to Cement Ratio	Air Content Percentage
4500 and greater	660	0.44	0~6
3500 to less than 4500	560	0.44	0~6
3000	560	0.49	6.5±1.5
2200	470	0.60	0~6
1500	380	0.60	0~6

Table 7.5: Concrete basic mixture design requirements when supplementary cementitious materials are used, as specified by ITD Spec. Book (Table 703.02-8)

Concrete Class in (psi) (28-day)	Min. Cement Content (lb/yd³)	Minimum Supplementary Cementitious Material (SCM) Content (lb/yd³)	Max. Water to Cement Ratio	Air Content Percentage
4500 and greater	660	*6*	0.44	0~6
3500 to less than 4500	560	*6*	0.44	0~6
3000	560	*6*	0.49	6.5±1.5
2200	470	*6*	0.60	0~6
1500	380	*6*	0.60	0~6

During placement, slump should not vary more than one inch from the average. The acceptance of concrete is based on the parameters specified for a given concrete class. The acceptance of concrete strength is based on the results of 28-day compressive strength tests, performed on cylindrical specimens. The pay factor for the concrete is based on the attained percentage of the specified strength. Concrete mixture design, including the strength data, theoretical maximum density and setting time, should be provided by the contractor. The proposed mixture design should be tested according to AASHTO T 126. Basic mixture strength, determined on three cylindrical specimens should be equal to or exceed the design mixture strength. In addition to strength, air content should be reported for every mixture.

Fly ash used in mixtures to mitigate the risk of ASR should not have CaO content higher than two percent. Moreover, whenever fly ash is used, the fly ash source must be provided, along with cement source (mill chart).

[*6*] Minimal SCM content depends on the product. For fly ash and slag minimal content is 20 percent by weight of total cementitious material content (cement and SCM). For Silica Fume, minimum content is 7.5 percent by weight of total cementitious material.

Mixers used for concrete mixing, when loaded to their capacity, must be capable of combining the mixture components into a thoroughly mixed and uniform mass. Drum discharge of the mixer must be uniform. Minor adjustments to the mixture design due to moisture in the aggregate are not considered as changes in the mixture, and thus do not require approval or a new mixture design. Cement should be measured by weight, and kept separate from the aggregate, until mixing. Aggregates are measured by weight, within two percent of the required total weight. Aggregate should be stored so that the uniform grading and stable moisture content are maintained. Water content is measured either by volume or by weight, within one percent of the total required quantity. SCMs are measured by weight, within one percent of total required quantity. Dry admixtures are measured by weight, while liquid admixtures are measured either by weight or by volume. Admixtures should be dispersed in the mixing water prior to mixing.

Concrete should be placed as soon as possible after mixing, while it is plastic and workable. Concrete should be consolidated using vibration, while segregation should be avoided. Concrete surfaces should be kept completely and continuously moist during the curing period. A detailed list of standards for quality control of the concrete is provided in the Specification book, starting form Page 271.

7.3 SPECIMEN PREPARATION

Concrete mixtures from ITD districts' concrete projects were reproduced and mixed. Specimens for the tests were cast and then cured in accordance with ASTM C192, "Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory" [54]. The following subsection describes the concrete mixing procedure.

7.3.1 Mixing procedure

Before mixing, all the concrete constituents were brought to a temperature ranging from 68 to 86˚F [54]. The aggregate was proportioned and relocated to the laboratory prior to mixing, allowing for sufficient time to bring the aggregate to room temperature. Moisture absorption, moisture content, and specific gravity for coarse and fine aggregate were determined prior to proportioning and mixing in accordance to ASTM C127, "Standard Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregate" [52] and ASTM C128, "Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate" [53], respectively. Proportioning of aggregate and the mixing water was adjusted based on moisture absorption and the moisture content of the aggregate to bring the aggregate to a saturated surface dry (SSD) conditions. Powdered admixtures were mixed with a portion of the cement, while the liquid admixtures were added to the mixing water prior to mixing [54].

All concrete mixtures were prepared in a rotating drum mixer. On each mixing day, the mixing was preceded with "buttering" of the mixer with a small concrete batch, proportioned to closely represent the test batch. According to ASTM C192, the coarse aggregate was fed into the drum with a portion of the mixing water; the drum was run for a brief period to bring the aggregate to SSD condition. Fine aggregate, cementitious materials, and water were added into the drum with the mixer running. The mixing water was added to the mixture gradually until the designed slump was achieved. Note that the moisture content of coarse and fine aggregate varied depending on the location of the sampled aggregate in the barrel or bin. As such, slight modifications in mixing water was inevitable from batch to batch to achieve the required slump. After all ingredients were in the mixer, concrete was mixed for about three minutes, then left to rest for two minutes, and finally mixed for an additional three minutes. The mixer was discharged into a clean wheelbarrow and then re-mixed manually by a shovel or scoops to attain a uniform mixture and avoid segregation.

Fresh concrete quality control tests, namely: slump, air content and unit weight were performed based on ASTM C143, "Standard Test Method for Slump of Hydraulic-Cement Concrete" [60], ASTM C231, "Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method" [61], ASTM C138, "Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete" [62], respectively. Slump and the temperature of concrete were determined for every batch, while the unit weight and air content were determined for every other batch.

7.3.2 Casting specimens

PVC and metal molds were used to cast the specimens for this project. Prior to usage, molds were lightly coated with form-release oil. Cylindrical and prismatic specimens were cast for strength and drying shrinkage testing, successively. Cylindrical specimens were cast with the axis of the cylinder kept vertical, while the prismatic specimens were cast with the long axis horizontal. The number of lifts required for each type of specimen is provided in Table 7.6, depending on the method of consolidation, vibration versus rodding. Concrete with slump greater or equal to one inch was compacted either by rodding or by vibration, as per ASTM C192 [54]. In the case of mixtures with slump less than one inch, concrete was consolidated by vibration.

Table 7.6: The number of lifts required for casting different specimen types

Specimen Type and Size	**Number of Lifts of Approximate Equal Depth**
Cylinders: Diameter [in]	
3 or 4	2
6	3
Prisms: Depth [in]	
< 8 (rodding consolidation)	2
< 8 (vibration consolidation)	1

7.3.3 Specimen curing

After consolidation, specimens were finished with a trowel or a strike-off bar. To prevent excessive evaporation, freshly made specimens were covered with sheets of durable, impermeable plastic. Molds were removed 24 ± 8 hours after casting [54]. After demolding, specimens were moist-cured at temperature 73.5 ± 3.5 ˚F in the fog room at relative humidity (RH) level higher than 95 percent, as defined in ASTM C511, “Standard Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes” [63], until the time of the designated test. The University of Idaho transported the specimens from Washington State University for testing within three days of casting. During the transportation, special care was taken to have specimens protected from jarring and disturbance by cushioning material, as well as from moisture loss by wet burlap, as defined in ASTM C31, “Standard Practice for Making and Curing Concrete Test Specimens in the Field” [64]. The duration of transfer was approximately 15 minutes, which satisfies the standard requirements.

7.4 TESTING PLAN

The schedule for mixing, casting and testing concrete mixtures was developed based on the project's overall schedule as well as the project objectives. The number of specimens required for each test is shown in Table 7.7.

Table 7.7: Number of specimens for each material characterization test and for each test date

Material Test	Corresponding Standard	Number of Specimen for Testing			
		7-day	14-day	28-day	90-day
Modulus of Elasticity and Poisson's Ratio (*E*)	ASTM C469	3	3	3	3
Compressive Strength (f'_c)[7]	ASTM C39	4	4	4	4
Split Tensile Strength (f'_t)	ASTM C496	3	3	3	3
Modulus of Rupture (*MR*)	ASTM C239	3	3	3	3
Coefficient of Thermal Expansion (CTE)[8]	AASHTO T-336			3	
Drying shrinkage (ε_∞)[9]	ASTM C157	6			

7.5 LABORATORY TESTS

The specimens were cured until the time of testing. The following subsections describe each of the laboratory tests performed on the samples.

7.5.1 Compressive strength

The compressive strength (f'_c) test was performed in accordance with ASTM C39, "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens" [45]. The tests were performed on 6-inch diameter and 12-inch height cylindrical specimens, at 7, 14, 28 and 90-day ages. Four specimens from one batch were tested on each test day. Prior to testing, the diameter of each cylinder was determined as the average of two measurements at a right angle to each other, obtained by a caliper. Prior to testing, all specimens were capped on both ends

---

[7]Three of these specimens are the same specimens tested for elastic modulus.
[8]Experimental determination of CTE will be performed on specimens after 28-day age. More details on this test procedure can be found in subsection 5.5.5.
[9]Experimental determination of ε_∞ will be performed on specified ages. More details on this test procedure can be found in subsection 5.5.6.

with gypsum caps to provide a uniform surface for load distribution. The loading rate corresponded to 35 ± 7 psi/s stress rate on the specimen. The compressive load was applied until the load indicator showed an abrupt decrease and the specimen presented prominent crack patterns. Compressive strength was calculated as a quotient of the maximum load attained during the test by the surface area of the specimen, based on the average diameter measurement. After the test, the failure type as identified and reported as specified in ASTM C39.

7.5.2 Modulus of elasticity

Modulus of elasticity (E) tests were performed per the procedure outlined in ASTM C469, "Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression" [49]. The test procedure included the determination of the chord modulus of elasticity and the Poisson's ratio (ν) for concrete specimens. The test was performed on 6-inch cylindrical specimens at 7, 14, 28 and 90-day ages, prior to the f'_c tests. Three specimens from one batch were gypsum capped and tested on each test day. The displacement of each specimen was measured using a compressometer with dial gages capable of measuring to the nearest five millionths of an inch. The deformation for each sample was the average of displacements measured along two diametrically opposite gauge lines, parallel to the axis of the specimen and centered about the mid-height of the specimen were used. The dimensions of the specimen diameter were determined prior to testing as the average of two measurements obtained by a caliper. The measured height of the specimens included the gypsum caps, cast to ensure the uniform loading over the cross-sectional area as shown in Figure 7.1.

The specimen harnessed with the compressometer was placed in the uniaxial compression machine and loaded at least four times: the first time to validate the performance of the gauges and introduce necessary corrections, and subsequently to collect the stress-strain data. The calculations were based on the results of three loading trials after the correct performance of gauges was confirmed. A loading rate of 35 ± 7 psi/s was utilized for the compressive strength tests. The specimens were loaded up to 40 percent of the average ultimate load attained by breaking two companion specimens. The modulus of elasticity was calculated to the nearest 50,000 psi using following equation,

$$E = \frac{(S_2 - S_1)}{(\epsilon_2 - 0.000050)}$$

Where, E = chord modulus of elasticity, S_2 = stress corresponding to 40% of ultimate load, S_1 = stress corresponding to a longitudinal strain, ϵ_1, of 50 millionths, ϵ_2 = longitudinal strain produced by stress S_2,

Poisson's ratio (ν) is calculated to the nearest 0.01, based on the following equation,

$$\nu = \frac{(\epsilon_{t2} - \epsilon_{t1})}{(\epsilon_2 - 0.000050)}$$

Where, ν = Poisson's ratio, ϵ_{t2} = transverse strain at mid-height of the specimen which corresponds to stresses S_2, ϵ_{t1} = transverse strain at mid-height of the specimen which corresponds to stresses S_1,

Figure 7.1: Compressometer setup for modulus of elasticity and Poisson's ratio testing

7.5.3 Indirect split tensile strength

The indirect split tensile strength (f'_t) test was performed in accordance with ASTM C496, "Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens" (ASTM C496) [58]. The test was performed on 6-inch diameter cylindrical specimens, at 7, 14, 28 and 90-day ages. Three specimens from one batch were tested on each test day. The test applies a radial compressive force along the length of the cylindrical concrete specimen, which induces indirect tensile stresses. Thin plywood bearing strips were used to provide a uniform load distribution along the length of the cylinders. The load was applied at a constant rate of 100 to 200 psi/minute. The splitting tensile strength of the specimen is calculated by the following equation.

$$T = \frac{2P}{\pi LD}$$

Where *T* represents the indirect split tensile strength, *P* is the peak load on the test, *D* is the diameter of the specimen, and *L* is the specimen length. Diameter and length of each specimen are reported as the average of two values obtained using a caliper. The experimental setup for the split tensile strength test is shown in Figure 7.2.

Figure 7.2: Indirect split tensile strength experimental setup

7.5.4 Modulus of rupture

The modulus of rupture (MR) or flexural strength of concrete was determined according to the procedure outlined in ASTM C293, “Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading)” [65]. The test was performed on beam specimens with dimensions 6 x 6 x 20 inches, at 7, 14, 28 and 90-day ages. Three specimens from one batch were tested on each test day at the University of Idaho. Testing of the MR on moist-cured specimens was performed within five minutes after removing the specimens from the fog room, as recommended in ASTM C293.

The MR of a beam specimen is determined by loading a simply supported beam with a center-point loading. The load was applied at a constant rate ranging from 125 to 175 psi/min to the breaking point. The modulus of rupture was calculated by the following equation,

$$MR = \frac{3PL}{2bd^2}$$

Where *MR* is the modulus of rupture, *P* is the maximum applied load, *L* is the span length, *b* and *d* are the average width and depth of the specimen, respectively. Length, width, and depth of each specimen are reported as the average of three values obtained using a caliper. Figure 7.3 presents the experimental setup used for MR determination.

Figure 7.3: Modulus of rupture testing experimental setup

7.5.5 Coefficient of thermal expansion

The concrete thermal expansion coefficient (CTE) is used to determine concrete length and volumetric changes when exposed to a uniform temperature change. The CTE is determined according to a procedure outlined in AASHTO T 336-15, "Standard Method of Test for Coefficient of Thermal Expansion of Hydraulic Cement Concrete" [66]. The test is performed on 4-inch diameter cylindrical specimens, at 28 days of age or more. The CTE is determined for two specimens from each mixture. Calibration and verification specimens with a known CTE were received from the Federal Highway Administration (FHWA) for the calibration of the testing apparatus and determination of the correction factor. Calibration and the verification of the test procedure and testing apparatus are necessary for accurate CTE testing.

For this test, concrete specimens are conditioned under water in a temperature-controlled water bath at two temperature levels, while the expansion caused by the temperature change is measured. The specimen is initially conditioned at the water temperature of 50˚F until three consistent measurements of specimen length are obtained within 30 minutes (measurements are taken every 10 minutes). Subsequently, the temperature of the water bath is set at 122˚F and the specimen is further conditioned until its length is consistent, according to three consecutive measurements performed in 10-minute intervals. Finally, the water bath temperature is set at 50˚F and the specimen is conditioned again at this temperature until its measured length is consistent, as previously described. As per AASHTO T336-15, a consistent length is achieved when the difference between two subsequent measurements is less than 0.000005 in. The CTE is calculated by dividing the corrected length change by the change in temperature and the initial length of the specimen. If the values of CTE determined based on two tests differ by less than 0.2 microstrains/˚F, the test result is the average of the CTE obtained from the two tests. Otherwise, one or more additional tests should be performed, until two subsequent tests yield in CTE measurements that differ by less than 0.2 microstrains/˚F. The CTE test experimental setup is shown in Figure 7.4.

Figure 7.4: Photo showing the temperature-controlled water bath used for CTE testing (WSU).

7.5.6 Drying shrinkage

The drying shrinkage (ε_∞) test was performed based on the procedure outlined in ASTM C157, “Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete” [67]. Tests were performed on prismatic specimens with dimensions 2 by 2 by 12 inches on six specimens for each mixture. The test procedure determines the length change of prismatic specimens due to environmental conditions. Specimens were demolded 24 hours after casting, placed in lime-saturated water at 73˚F for a 15-minute period, wiped with a damp cloth, after which the initial length measurement was taken. Specimens were then cured in a curing room at 73˚±2 ˚F upon 28 days of age. After the curing period, another length measurement was taken, after which specimens were kept in a drying room and cured in air for the rest of the test. Length measurements of each specimen are performed after the periods of air curing of 4, 7, 14, 28 days and after 8, 16, 32 and 64 weeks. Length change is determined by the following equation,

$$\Delta L_x = \frac{CRD - intial\ CRD}{G} * 100$$

Where ΔL_x represents the length change of the specimen at any age in percent, *CRD* the difference between the comparator reading of the specimen length and the reference bar at any age, and *G* represents the gage length. Figure 7.5 presents the experimental setup used for the determination of drying shrinkage based on length change.

Figure 7.5: Experimental determination of drying shrinkage based on length change

7.6 TEST RESULTS

The following subsections will provide the summary of the results of all tests performed on the concrete mixtures from all districts.

7.6.1 Fresh Properties

Table 7.8 lists the mixture descriptions and specified producers of cementitious material, as defined in mixture designs from each district. The fresh properties of all mixtures are presented in Table 7.9. It is shown that all the slump test values, the concrete weight, and air entrained percentages are in good agreement with ITD specifications which indicates that the concrete mixtures developed at the lab have good quality control and represent the concrete developed in the field.

Table 7.8: Mixture Description and specified producers of cementitious material, as defined in received mixture designs

District Number with Mixture Description (if more mixture designs were provided by the same district**)**	**Cement Type Specified by Mixture Design**	**Fly Ash Type Specified by Mixture Design**
M1 (District 1, Structural Mixture)	Lafarge Type I/II	No Fly Ash
M2 (District 1, Lookout Paving Mixture (Centralia))	Lafarge Type I	Centralia
M3 (District 2, Thain Road Paving Mixture (Atlas))	Ash Grove Type I/II	Sundance
M4 (District 2, US-95 Race Creek Bridge, Structural Mixture (Accumix))	Ash Grove Type I/II	ENX Genesee Class F
M5 (District 3, I-84 Paving Mixture)	Ash Grove Type I	Type F (Bridger), Headwaters
M6 (District 5, US-90 Paving Mixture)	Ash Grove Type I /II	Naavajo

Table 7.9: Fresh properties of all mixtures

Mixture	**M1**		**M2**		**M3**		**M4**		**M5**		**M6**	
	Lab.	**Field**	**Lab.**	**Field**	**Lab.**	**Field**	**Lab.**	**Field**	**Lab.**	**Field**	**Lab.**	**Field**
Slump (inch)	3.5	3.5	1.25	1.5	4	4.5	5.25	5.75	2.5	1.75	3.25	3.25
Entrained Air (%)	6.7	6.5	4.2	5.3	5.2	2.9	5.2	6.1	6.5	5.9	6	5.7
Unit weight (lbs/ft^3)	142.9	140.7	148.1	144	144.6	148.6	145.3	143.7	140.3	142.5	140.3	143.3

7.6.2 District 1 (two mixtures M1 and M2)

Table 7.10 presents the results of the mechanical tests for the mixtures design from District 1. The average values of the mechanical properties, namely: modulus of elasticity (*E)*, Poisson's ratio (ν), compressive strength (f'_c), splitting tensile strength (f'_t) and modulus of rupture *(MR)* are listed for the four test dates with the corresponding standard deviations. Also, the thermal conductivity of the mixture is listed in Table 7.10.

Table 7.10: Results of the mechanical tests and thermal conductivity for the M1, Structural mixture from District 1.

Mechanical property	Test day			
	7-day	**14-day**	**28-day**	**90-day**
Modulus of elasticity, *E* [$\times 10^6$ psi]	3.55	3.80	4.25	4.55
Standard deviation [psi]	100,000	135,000	140,000	210,000
Poisson's ratio, ν	0.17	0.16	0.16	0.17
Standard deviation	0.03	0.02	0.04	0.01
Compressive strength, f'_c [psi]	4,040	4,630	4,870	5,270
Standard deviation [psi]	180	200	160	180
Splitting tensile strength, f'_t [psi]	410	465	490	510
Standard deviation [psi]	40	15	40	25
Modulus of rupture, *MR* [psi]	630	655	715	730
Standard deviation [psi]	35	30	15	20
Thermal Conductivity BTU/hr-ft-deg F [$\times 10^{-6}$]	4.83			

Figure 7.6 presents the results of the drying shrinkage test in terms of length change percentage for the structural mixture design from the District 1. Positive values of drying shrinkage strain are associated with swelling, while the negative values denote shrinkage. Drying shrinkage tests for this mixture are still in progress and the measurements after 32 and 64 weeks of air curing are yet to be recorded.

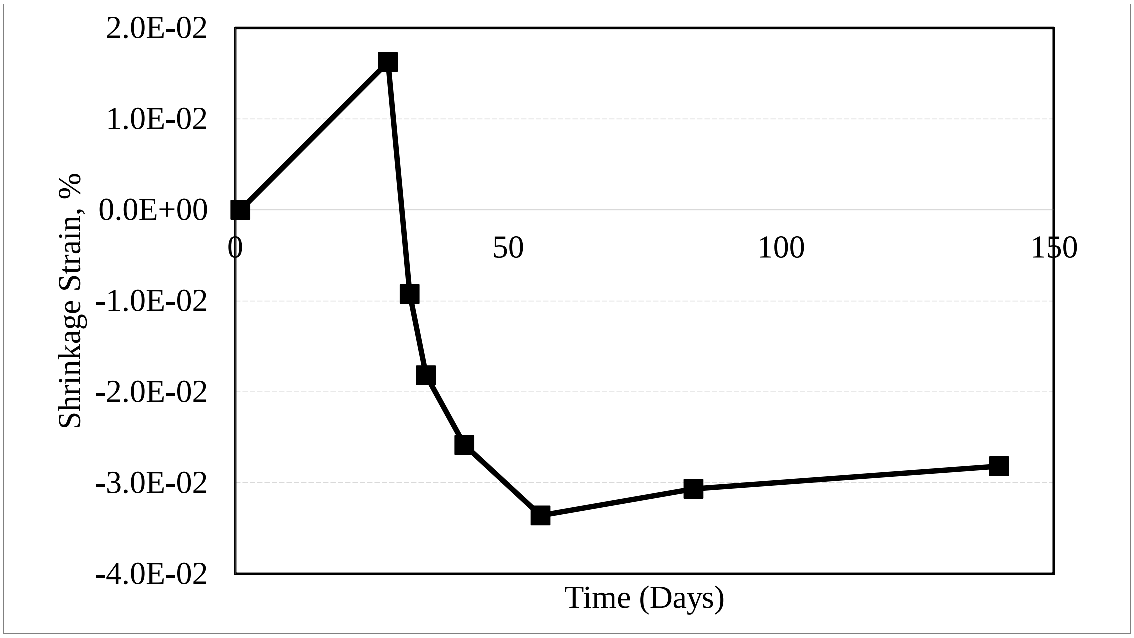


Figure 7.6: Drying shrinkage strain development over time, based on length change measurements for the Structural mixture from District 1

The second mixture (M2) from District 1 (Centralia) was used at the Lookout paving project (I-90 Mullan to Montana State Line). In order to reproduce the Centralia mixture in the laboratory as close as possible to the fresh concrete used in the field for paving, the field tests results were obtained from District 1 and are provided in Appendix C. Table 7.11 shows the results of laboratory and field tests on fresh concrete.

Table 7.11: Results of laboratory and field tests on fresh concrete for the Centralia mixture design from District 1

Fresh concrete properties	Laboratory test results	ITD's on-site test results
Slump (inch)	Range: ¾ to 1 ¼ Ave.: 1 ¼	Range: ¼ to 3 ¼", Ave: 1 ½
Entrained Air (%)	Range: 3.9 to 4.5 Ave.: 4.2	Range: 3.5 to 7.1, Ave.: 5.3
Unit weight (lb/ft^3)	Range: 146.8 to 149.2 Ave.: 148.1	Range:141.3 to 144.6 Ave.: 144.0

Table 7.12 presents the results of the mechanical tests for the Centralia mixture design from the District 1. The average values of the mechanical properties with the corresponding standard deviations are given for the four test dates. Also, the thermal conductivity of the mixture is listed in Table 7.12.

Table 7.12: Results of the mechanical tests and thermal conductivity for the Centralia mixture from District 1

Mechanical property	**Test day**			
	7-day	**14-day**	**28-day**	**90-day**
Modulus of elasticity, *E* [$\times 10^6$ psi]	3.85	3.90	4.15	5.15
Standard deviation [psi]	245,000	400,000	365,000	290,000
Poisson's ratio, ν	0.16	0.15	0.14	0.21
Standard deviation	0.02	0.01	0.01	0.05
Compressive strength, f'_c [psi]	4,830	5,470	5,510	6,560
Standard deviation [psi]	130	210	240	235
Splitting tensile strength, f'_t [psi]	520	505	535	645
Standard deviation [psi]	35	25	30	55
Modulus of rupture, *MR* [psi]	750	755	895	890
Standard deviation [psi]	50	5	45	50
Thermal Conductivity BTU/hr-ft-deg F [$\times 10^{-6}$]	3.75			

Figure 7.7 presents the results of the drying shrinkage test for the Centralia mixture design from the District 1. Drying shrinkage tests for this mixture are still in progress and the measurements after 32 and 64 weeks of air curing are yet to be recorded.

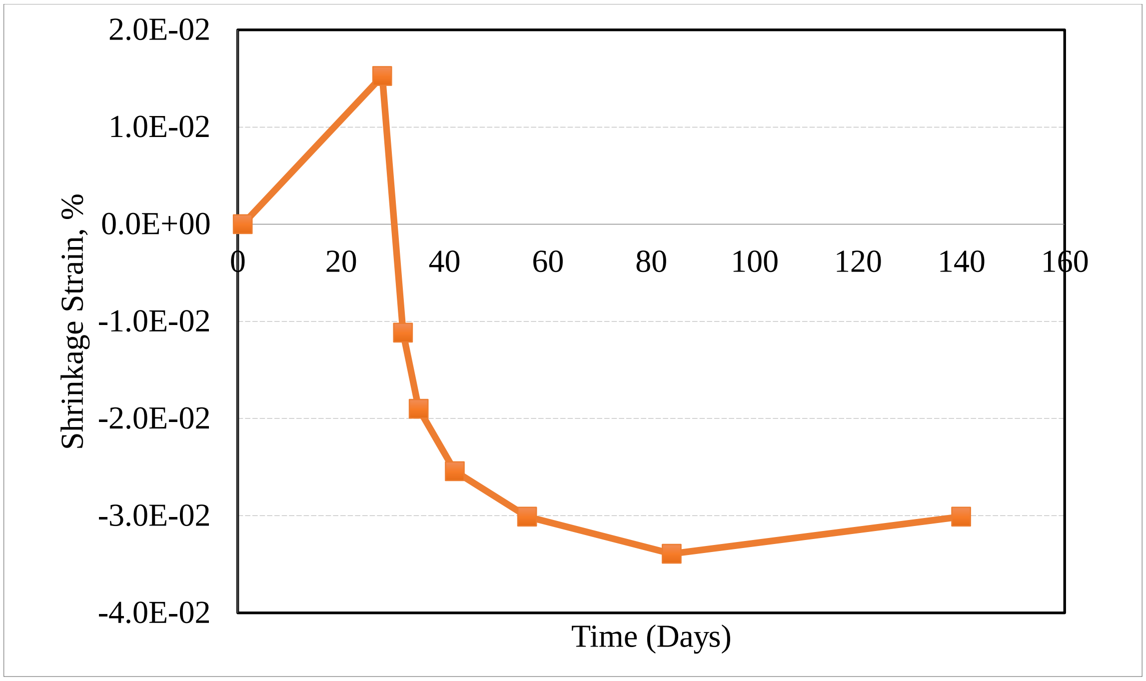


Figure 7.7: Drying shrinkage strain development over time, based on length change measurements for the Centralia mixture from District 1

7.6.3 District 2 (two mixtures M3 and M4)

Field test results on fresh concrete for Atlas mixture were collected prior to mixing. The Atlas mixture was batched at WSU on June 9th and 10th 2016. Table 7.13 shows the results of both laboratory and field tests performed on fresh concrete for Atlas mixture design.

Table 7.13: Results of laboratory and field tests on fresh concrete for the Atlas mixture design from District 2

Fresh concrete properties	**Laboratory test results**	**ITS's on-site test results**
Slump (inch)	Range: 3 to 4 ¾ Ave.: 4	Range: 4 to 5 Ave.: 4 ½
Entrained Air (%)	Range: 4.3 to 6.0 Ave.: 5.2	Range:1 to 5 Ave: 2.9
Unit weight (lbs/ft^3)	Range: 142.5 to 146.5 Ave.: 144.6	Range: 145.1 to 150.4 Ave.: 148.6

The results of the mechanical tests for the Atlas mixture design from the District 2 are provided in Table 7.14. The average values of the modulus of elasticity (*E)*, Poisson's ratio (ν), compressive strength *(f'_c)*, splitting tensile strength *(f'_t)* and modulus of rupture *(MR)* are listed for the four test dates with their standard deviations. Also, the thermal conductivity of the mixture is listed in Table 7.14.

Table 7.14: Results of the mechanical tests and thermal conductivity for the Atlas mixture from District 2

Mechanical property	Test day			
	7-day	**14-day**	**28-day**	**90-day**
Modulus of elasticity, *E* [$\times 10^6$ psi]	3.30	4.10	3.70	4.65
Standard deviation [psi]	100,000	195,000	220,000	155,000
Poisson's ratio, ν	0.18	0.18	0.18	0.22
Standard deviation	0.01	0.02	0.02	0.01
Compressive strength, f'_c [psi]	3,760	5,130	5,160	5,830
Standard deviation [psi]	200	180	260	170
Splitting tensile strength, f'_t [psi]	390	475	470	575
Standard deviation [psi]	25	20	25	30
Modulus of rupture, *MR* [psi]	595	660	785	865
Standard deviation [psi]	55	15	15	45
Thermal Conductivity BTU/hr-ft-deg F [$\times 10^{-6}$]	4.51			

Figure 7.8 presents the results of the drying shrinkage test determined by measuring the length change percentage for the Atlas mixture design from the District 2. Drying shrinkage tests for this mixture are still in progress and the measurements after 32 and 64 weeks of air curing are yet to be performed.

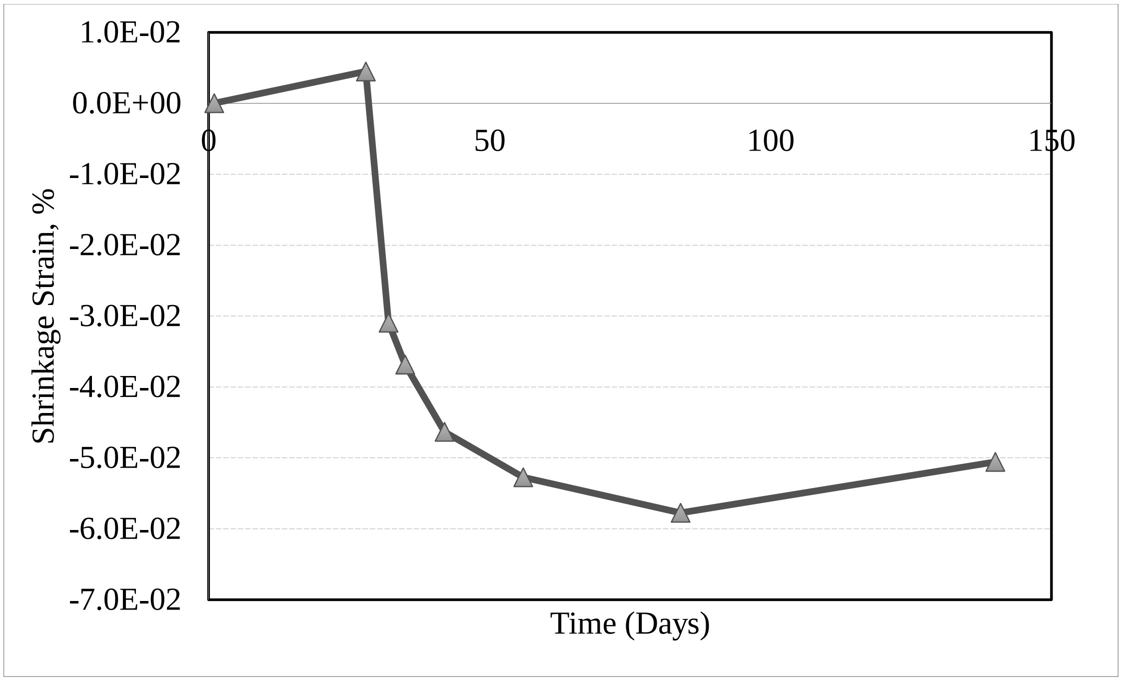


Figure 7.8: Drying shrinkage strain development over time, based on length change measurements for the Atlas mixture from District 2

The mixture design Accumix from District 2 was collected from the District 2 and used as a reference for mixing. Both field and laboratory results of fresh concrete tests are provided in Table 7.15.

Table 7.15: Results of laboratory and field tests on fresh concrete for Accumix mixture from District 2

Fresh concrete properties	**Laboratory test results**	**ITS's on-site test results**
Slump (inch)	Range: 3 ¾ to 5 ¾ Ave.: 5 ¼	Range: 3 ¾ to 7 ¾ Ave.: 5 ¾
Entrained Air (%)	Range: 4.5 to 6.1 Ave.: 5.2	Range: 5.2 to 7.5 Ave: 6.1
Unit weight (lbs/ft^3)	Range: 143.6 to 146.9 Ave.: 145.3	Range: 140.9 to 145.5 Ave.: 143.7

Table 7.16 presents the results of the mechanical tests and thermal conductivity for the Accumix mixture design from the District 2.

Table 7.16: Results of the mechanical tests and thermal conductivity for the Accumix mixture from District 2

Mechanical property	**Test day**			
	7-day	**14-day**	**28-day**	**90-day**
Modulus of elasticity, *E* [$\times 10^6$ psi]	4.65	4.35	4.90	5.50
Standard deviation [psi]	105,000	140,000	150,000	170,000
Poisson's ratio, ν	0.19	0.19	0.20	0.21
Standard deviation	0.02	0.01	0.03	0.01
Compressive strength, f'_c [psi]	5,340	5,610	6,900	7,560
Standard deviation [psi]	190	300	125	410
Splitting tensile strength, f'_t [psi]	510	510	540	680
Standard deviation [psi]	25	25	60	45
Modulus of rupture, *MR* [psi]	795	790	810	895
Standard deviation [psi]	10	25	40	10
Thermal Conductivity BTU/hr-ft-deg F [$\times 10^{-6}$]	5.38			

Figure 7.9 shows the results of the drying shrinkage test in terms of length change percentage for the Accumix mixture design from the District 2. Drying shrinkage tests for this mixture are still in progress and the measurements after 32 and 64 weeks of air curing will be recorded based on the experimental schedule.

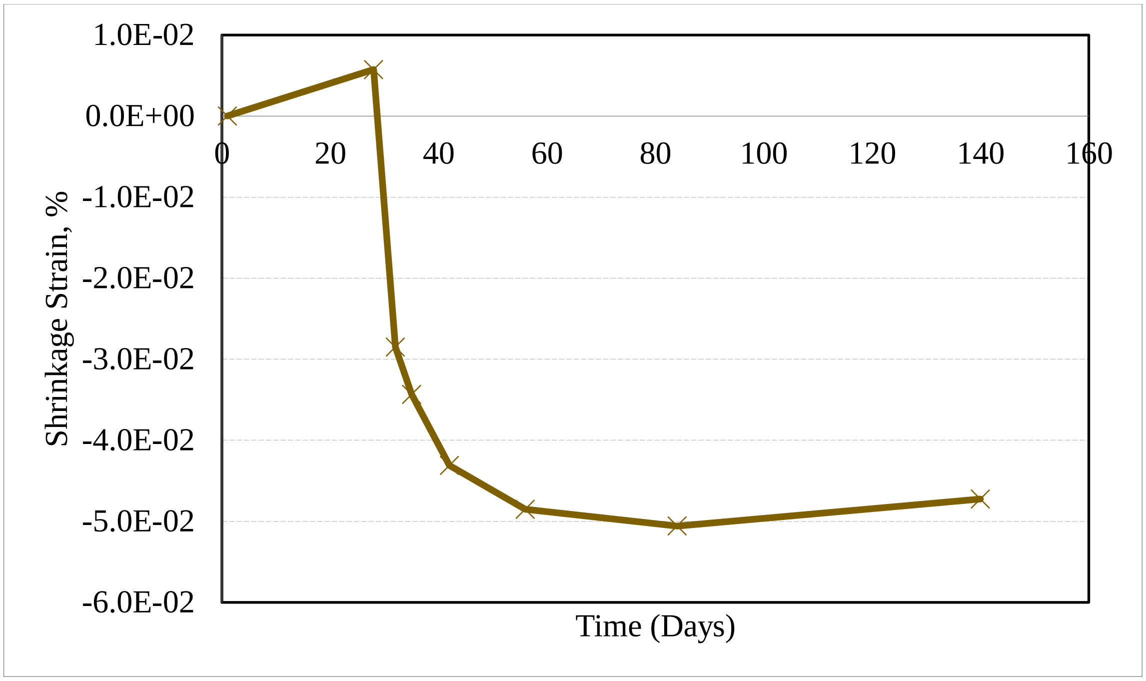


Figure 7.9: Drying shrinkage strain development over time, based on length change measurements for the Accumix mixture from District 2

7.6.4 District 3

District 3 has provided one paving mixture design, used to pave a section of I-84, at Meridian RD 1C and 1-84, and Meridian 1C to Five-Mile Road A010(939) and A013(057). Field results from District 3 were collected and listed in Table 7.17. The results of the fresh concrete tests from both field and the laboratory are summarized in Table 7.17.

Table 7.17: Results of laboratory and field tests on fresh concrete for the concrete mixture design from District 3

Fresh concrete properties	Laboratory test results	ITS's on-site test results
Slump (inch)	Range: 1¼ to 3 ¼ Ave.: 2½	Range: ½ to 4½ Ave.: 1 ¾
Entrained Air (%)	Range: 6 to 7 Ave.: 6.5	Range: 4.4 to 7 Ave: 5.9
Unit weight (lbs/ft^3)	Range: 139.1 to 141.3 Ave.: 140.3	Range: 138.5 to 144.9 Ave.: 142.5

The results of the mechanical tests for the mixture from the District 3 are provided in Table 7.18. The average values of *E, v*, f'_c, f'_t and *MR* are summarized for the four test dates with their standard deviations.

Table 7.18: Results of the mechanical tests for the mixture from District 3

Mechanical property	**Test day**			
	7-day	**14-day**	**28-day**	**90-day**
Modulus of elasticity, *E* [$\times 10^6$ psi]	2.75	3.20	3.60	3.80
Standard deviation [psi]	115,000	145,000	120,000	150,000
Poisson's ratio, *v*	0.14	0.14	0.15	0.16
Standard deviation	0.02	0.03	0.03	0.03
Compressive strength, f'_c [psi]	3,890	4,510	5,590	6,398
Standard deviation [psi]	170	200	220	350
Splitting tensile strength, f'_t [psi]	425	440	515	600
Standard deviation [psi]	20	15	15	30
Modulus of rupture, *MR* [psi]	650	755	745	880
Standard deviation [psi]	5	55	30	50

Figure 7.10 presents the results of the drying shrinkage test in terms of length change percentage and total shrinkage for the mixture design from the District 3. Drying shrinkage tests for this mixture are still in progress and the measurements after 32 and 64 weeks of air curing are yet to be recorded.

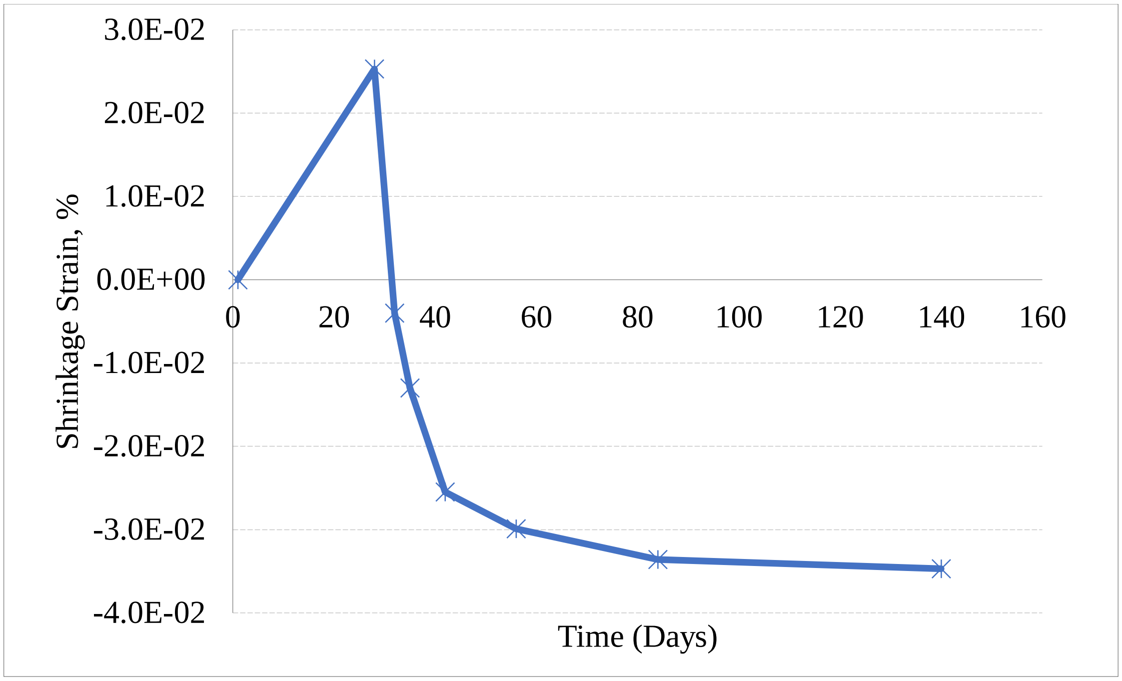


Figure 7.10: Drying shrinkage strain development over time, based on length change measurements for the mixture from District 3

7.6.5 District 5

The results of the fresh concrete tests from both field and the laboratory mixes from District 5 are summarized in Table 7.19.

Table 7.19: Results of laboratory and field tests on fresh concrete for the concrete mixture design from District 5

Fresh concrete properties	Laboratory test results	ITS's on-site test results
Slump (inch)	Range: 2 ½ to 5 Ave.: 3 ¼	Range: 2 ½ to 3½ Ave.: 3 ¼
Entrained Air (%)	Range: 3.5 to 8 Ave.: 6	Range: 4.7 to 6 Ave: 5.7
Unit weight (lbs/ft^3)	Range: 134.8 to 146.16 Ave.: 140.3	Range: 142.6 to 145.6 Ave.: 143.32

Table 7.20 shows the results of the mechanical tests for the mixture from District 5. The average values of the mechanical properties are listed for the three test dates with their corresponding standard deviations.

Table 7.20: Results of the mechanical tests for the mixture from District 5

Mechanical property	Test day			
	7-day	**14-day**	**28-day**	**90-day**
Modulus of elasticity, *E* [$\times 10^6$ psi]	4.03	3.75	4.32	4.03
Standard deviation [psi]	45,686	331,891	33,253	229,049
Poisson's ratio, ν	0.14	0.16	0.16	0.16
Standard deviation	0.017	0.026	0.008	0.008
Compressive strength, f'_c [psi]	4,540	4,850	5,080	5930
Standard deviation [psi]	172.2	104.3	116.0	276.7
Splitting tensile strength, f'_t [psi]	420	434.4	514.4	573.8
Standard deviation [psi]	30.3	9	28	28.8
Modulus of rupture, *MR* [psi]	654.3	730.2	776	791.4
Standard deviation [psi]	28.9	48.2	35.1	84.9

Figure 7.11 presents the results of the drying shrinkage test in terms of length change percentage for the mixture design from the District 5. Drying shrinkage test for this mixture are still in progress and the measurements after 32 and 64 weeks of air curing are yet to be recorded.

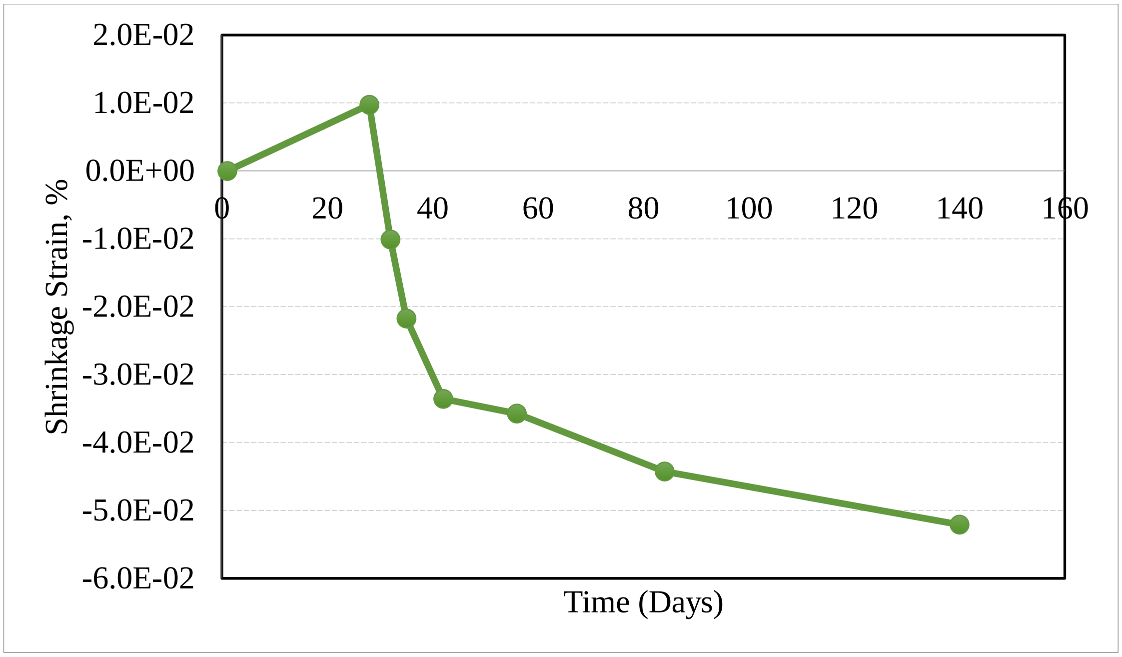
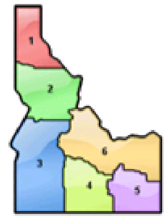


Figure 7.11: Drying shrinkage strain development over time, based on length change measurements for the mixture from District 5

7.7 IMPLEMENTATION OF PCC MATERIALS DATABASE ONTO AASHTOWARE PAVEMENT ME DESIGN SOFTWARE

The mechanical, thermal and durability properties obtained from this project were then used to create material properties database. A screen shot for the spreadsheets database is shown in Figure 7.12. This is a draft material input database to be implemented in AASHTOWare Pavement ME Design (ME) software. The database will be updated with more long-term test results and one more mix from District 1 and one more form District 6. This PCC database is currently under scrutiny and development. Once the rest of the mixtures are fully developed and tested, the results will be coupled with the existing database and merged with the current ITD ME Design Database to form a combined database to be implemented on AASHTOWare Pavement ME Design (ME) software. The main screen of the current ITD ME database is shown in Figure 7.13.

AASHTOWare Pavement ME Design
Idaho PCC Mixes
ITD Research Project RP253



District Number with Mixture Description (Please click on the Mix for Details)	Cement Type Specified by Mixture Design	Fly Ash Type Specified by Mixture Design	PCC RAW Data
District 1, Structural Mixture	Lafarge Type I/II	No Fly Ash	RAW DATA
District 1, Lookout Paving Mixture	Lafarge Type I	Centralia	RAW DATA
District 1, I-90 Paving Mixture	Lafarge Type I	Sundance	RAW DATA
District 2, Thain Road Paving Mixture	Ash Grove Type I/II	Sundance	RAW DATA
District 2, US-95 Race Creek Bridge	Ash Grove Type I/II	ENX Genesee Class F	RAW DATA
District 3, I-84 Paving Mixture	Ash Grove Type I	Type F, Headwaters	RAW DATA
District 5, US-90 Paving Mixture	Ash Grove Type I /II	Naavajo	RAW DATA

Figure 7.12: Main Screen of the AASHTOWare Pavement ME Design Idaho PCC Mixes database

The screenshots of the PCC materials input database for each mixture are presented in Appendix D. An example of jointed plain concrete pavement (JPCP) design was completed for each paving mixtures from the database using AASHTOWare Pavement ME design software. Figure 7.14 shows the main screen of the ME Software which shows the layout the software for a rigid pavement design. The ME software requires the traffic, climate and PCC material properties for the design of a rigid pavement. For all the designs, a JPCP section consisting of 5 layers (a top layer as PCC with 3 non-stabilized base layer, and a subgrade) from Interstate Highway I-84 near Cotterel, Idaho was selected. The climate data is selected from nearby weather station at Boise Air Terminal, Boise, Idaho. Figure 7.15 shows the traffic inputs for the selected road section. The traffic data is taken from "Traffic Weigh-In-Motion (WIM) Selection Table (Traffic Volume Characteristics and No. of Axles)" in the ITD Database for the ME Pavement Design Guide (ITD Research Project RP193). Figure 7.16

shows the climate data inputs for the weather station at Boise Air terminal, Boise, Idaho. The only inputs for the climate data is the coordinates of the selected road section and the software will load the required annual and monthly climatic data for the design. The JPCP design properties used for this design is shown in the Figure 7.17. While performing the design of the rigid pavement using AASHTOWare Pavement ME design software, it allows the users to use 3 levels of input based on the data availability. Level 1 requires the 7, 14, 28, and 90-day PCC modulus of rupture and elastic modulus whereas the level 3 only requires 28-day PCC compressive strength or modulus of rupture and 28-day PCC elastic modulus. So for each mixtures, design was conducted with input level 1 and 3 to see the differences in the design.

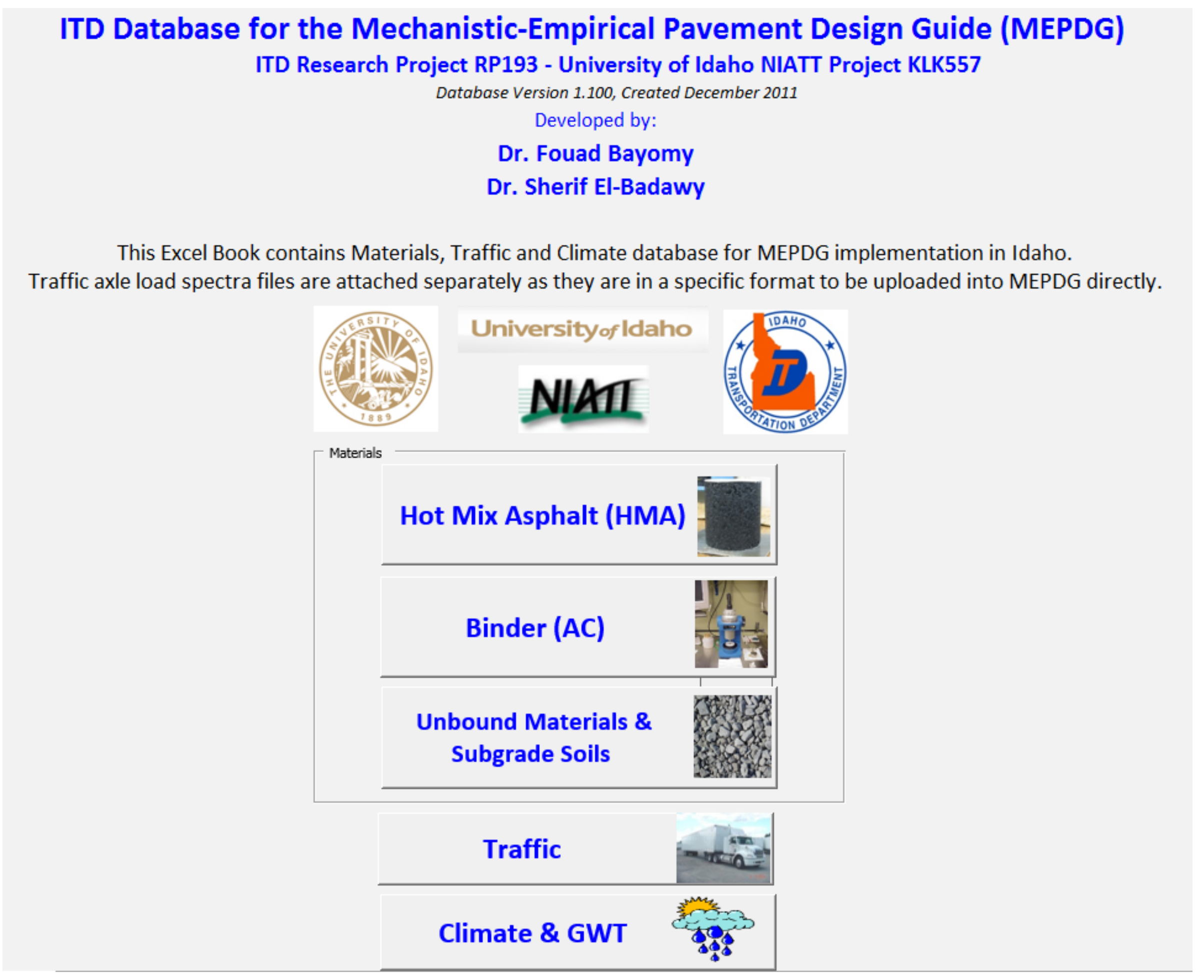


Figure 7.13: ITD database for the AASHTOWare Pavement ME Design Software (ITD research report RP 193-Implementation of the MEPDG for flexible pavements in Idaho)

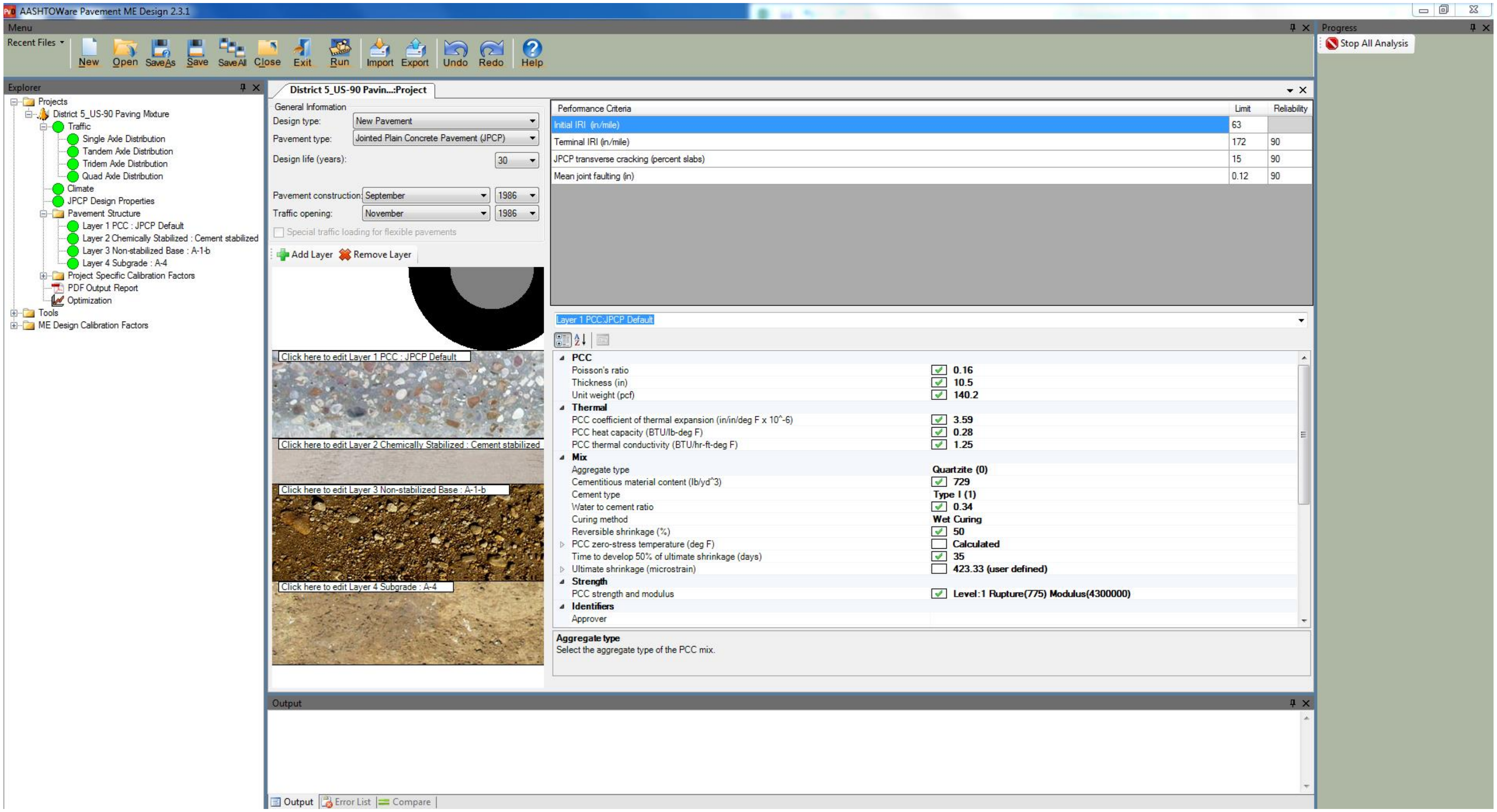


Figure 7.14: Main screen of AASHTOWare Pavement ME Design Software

Tabular Representation of Traffic Inputs

Volume Monthly Adjustment Factors

Level 3: Default MAF

Month	Vehicle Class 4	5	6	7	8	9	10	11	12	13
January	1.2	0.8	1.0	0.3	1.7	1.1	0.7	2.0	1.7	1.0
February	2.2	0.8	1.6	0.8	1.9	1.1	1.4	1.9	1.6	1.3
March	1.2	0.9	2.2	1.4	1.5	0.9	2.9	1.1	1.3	1.5
April	0.7	0.5	1.0	2.7	0.6	0.6	1.8	0.6	0.7	1.0
May	0.4	0.6	0.3	0.1	0.5	0.8	0.2	0.6	0.6	0.7
June	0.4	0.7	0.5	0.1	0.6	0.8	0.2	0.5	0.6	0.8
July	0.4	0.8	1.4	0.8	0.7	0.8	0.3	0.5	0.6	0.8
August	0.3	0.6	1.4	2.8	0.5	0.5	1.5	0.2	0.4	0.8
September	0.9	0.8	1.2	2.8	0.8	0.6	1.6	0.3	0.5	0.7
October	1.3	1.9	0.5	0.1	1.5	1.7	0.5	1.0	1.1	1.3
November	1.4	1.8	0.4	0.0	1.0	1.7	0.5	1.2	1.2	1.2
December	1.5	1.6	0.4	0.0	0.8	1.5	0.4	2.2	1.7	0.9

Distributions by Vehicle Class

Vehicle Class	AADTT Distribution (%) (Level 3)	Growth Factor Rate (%)	Growth Factor Function
Class 4	1.03%	3%	Linear
Class 5	5.96%	3%	Linear
Class 6	3.86%	3%	Linear
Class 7	7.2%	3%	Linear
Class 8	4.56%	3%	Linear
Class 9	52.35%	3%	Linear
Class 10	15.06%	3%	Linear
Class 11	1.45%	3%	Linear
Class 12	1.33%	3%	Linear
Class 13	7.2%	3%	Linear

Truck Distribution by Hour

Hour	Distribution (%)	Hour	Distribution (%)
12 AM	2.3%	12 PM	5.9%
1 AM	2.3%	1 PM	5.9%
2 AM	2.3%	2 PM	5.9%
3 AM	2.3%	3 PM	5.9%
4 AM	2.3%	4 PM	4.6%
5 AM	2.3%	5 PM	4.6%
6 AM	5%	6 PM	4.6%
7 AM	5%	7 PM	4.6%
8 AM	5%	8 PM	3.1%
9 AM	5%	9 PM	3.1%
10 AM	5.9%	10 PM	3.1%
11 AM	5.9%	11 PM	3.1%
		Total	100%

Axle Configuration

Traffic Wander	
Mean wheel location (in.)	18
Traffic wander standard deviation (in.)	10
Design lane width (ft)	12

Axle Configuration	
Average axle width (ft)	8.5
Dual tire spacing (in.)	12
Tire pressure (psi)	120

Average Axle Spacing	
Tandem axle spacing (in.)	51.6
Tridem axle spacing (in.)	49.2
Quad axle spacing (in.)	49.2

Wheelbase: Value Type / Axle Type	Short	Medium	Long
Average spacing of axles (ft)	12	15	18
Percent of Trucks (%)	33	33	34

Number of Axles per Truck

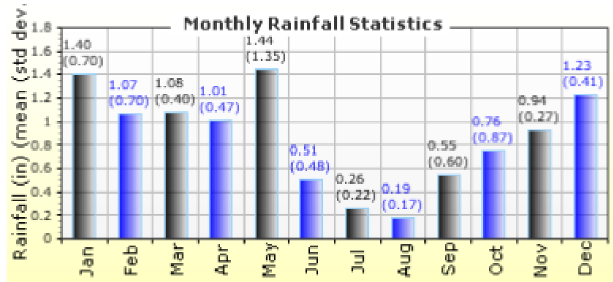
Vehicle Class	Single Axle	Tandem Axle	Tridem Axle	Quad Axle
Class 4	1.59	0.34	0	0
Class 5	2	0	0	0
Class 6	1	1	0	0
Class 7	1	0.22	0.83	0.1
Class 8	2.52	0.6	0	0
Class 9	1.25	1.87	0	0
Class 10	1.03	0.85	0.95	0.26
Class 11	4.21	0.29	0.01	0
Class 12	3.24	1.16	0.07	0.01
Class 13	3.32	1.79	0.14	0.02

Figure 7.15: Traffic Inputs for I-84 at mile-post 231.7 (WIM ID 117)

Climate Inputs

Climate Data Sources:

Climate Station Cities:	Location (lat lon elevation(ft))
BOISE, ID	43.56500 -116.22000 2814



Annual Statistics:

Mean annual air temperature (ºF)	53.06
Mean annual precipitation (in.)	10.44
Freezing index (ºF - days)	240.62
Average annual number of freeze/thaw cycles:	75.35

Water table depth (ft) 50.00

Monthly Climate Summary:

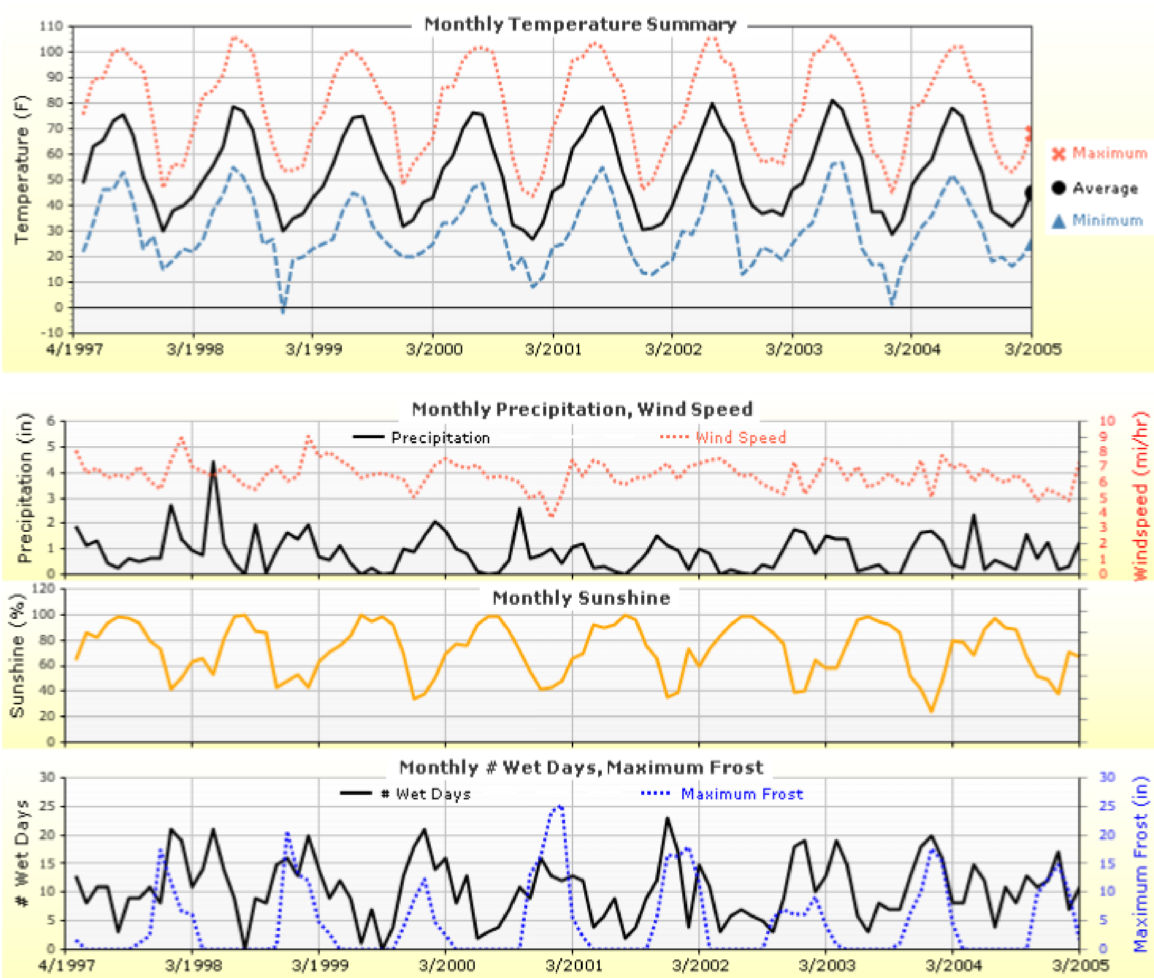


Figure 7.16: Climate data inputs for the weather station at Boise Air Terminal, Boise, Idaho

Design Properties

JPCP Design Properties

Structure - ICM Properties	
PCC surface shortwave absorptivity	0.85

Doweled Joints	
Is joint doweled ?	True
Dowel diameter (in.)	1.25
Dowel spacing (in.)	12.00

Tied Shoulders	
Tied shoulders	False
Load transfer efficiency (%)	-

PCC joint spacing (ft)	
Is joint spacing random ?	False
Joint spacing (ft)	15.00

Widened Slab	
Is slab widened ?	False
Slab width (ft)	12.00

PCC-Base Contact Friction	
PCC-Base full friction contact	True
Months until friction loss	240.00

Sealant type	Preformed
Erodibility index	5
Permanent curl/warp effective temperature difference (ºF)	-10.00

Figure 7.17: JCPC design properties

Except the top PCC layer, the other 4 layer properties and thickness was kept constant for all the designs. The properties of the second, third, and fourth non-stabilized base layer and the properties of subgrade layer are shown in Figure 7.18, Figure 7.19, Figure 7.20, and Figure 7.21, respectively.

Layer 2 Non-stabilized Base : A-1-a

Unbound	
Layer thickness (in.)	4.4
Poisson's ratio	0.35
Coefficient of lateral earth pressure (k0)	0.5

Modulus (Input Level: 3)

Analysis Type:	Modify input values by temperature/moisture
Method:	Resilient Modulus (psi)

Resilient Modulus (psi)
40000.0

Use Correction factor for NDT modulus?	-
NDT Correction Factor:	-

Identifiers

Field	Value
Display name/identifier	A-1-a
Description of object	Default material
Author	AASHTO
Date Created	1/1/2011 12:00:00 AM
Approver	
Date approved	1/1/2011 12:00:00 AM
State	
District	
County	
Highway	
Direction of Travel	
From station (miles)	
To station (miles)	
Province	
User defined field 2	
User defined field 3	
Revision Number	0

Sieve

Liquid Limit	6.0
Plasticity Index	1.0
Is layer compacted?	False

	Is User Defined?	Value
Maximum dry unit weight (pcf)	False	127.2
Saturated hydraulic conductivity (ft/hr)	False	5.054e-02
Specific gravity of solids	False	2.7
Optimum gravimetric water content (%)	False	7.4

User-defined Soil Water Characteristic Curve (SWCC)	
Is User Defined?	False
af	7.2555
bf	1.3328
cf	0.8242
hr	117.4000

Sieve Size	% Passing
0.001mm	
0.002mm	
0.020mm	
#200	8.7
#100	
#80	12.9
#60	
#50	
#40	20.0
#30	
#20	
#16	
#10	33.8
#8	
#4	44.7
3/8-in.	57.2
1/2-in.	63.1
3/4-in.	72.7
1-in.	78.8
1 1/2-in.	85.8
2-in.	91.6
2 1/2-in.	
3-in.	
3 1/2-in.	97.6

Figure 7.18: Properties of the second non-stabilized base layer

Layer 3 Non-stabilized Base : A-1-b

Unbound	
Layer thickness (in.)	5.3
Poisson's ratio	0.35
Coefficient of lateral earth pressure (k0)	0.5

Modulus (Input Level: 3)

Analysis Type:	Modify input values by temperature/moisture
Method:	Resilient Modulus (psi)

Resilient Modulus (psi)
38000.0

Use Correction factor for NDT modulus?	-
NDT Correction Factor:	-

Identifiers

Field	Value
Display name/identifier	A-1-b
Description of object	Default material
Author	AASHTO
Date Created	1/1/2011 12:00:00 AM
Approver	
Date approved	1/1/2011 12:00:00 AM
State	
District	
County	
Highway	
Direction of Travel	
From station (miles)	
To station (miles)	
Province	
User defined field 2	
User defined field 3	
Revision Number	0

Sieve

Liquid Limit	11.0
Plasticity Index	1.0
Is layer compacted?	False

	Is User Defined?	Value
Maximum dry unit weight (pcf)	False	123.7
Saturated hydraulic conductivity (ft/hr)	False	2.303e-03
Specific gravity of solids	False	2.7
Optimum gravimetric water content (%)	False	9.1

User-defined Soil Water Characteristic Curve (SWCC)	
Is User Defined?	False
af	5.8206
bf	0.4621
cf	3.8497
hr	126.8000

Sieve Size	% Passing
0.001mm	
0.002mm	
0.020mm	
#200	13.4
#100	
#80	20.8
#60	
#50	
#40	37.6
#30	
#20	
#16	
#10	64.0
#8	
#4	74.2
3/8-in.	82.3
1/2-in.	85.8
3/4-in.	90.8
1-in.	93.6
1 1/2-in.	96.7
2-in.	98.4
2 1/2-in.	
3-in.	
3 1/2-in.	99.4

Figure 7.19: Properties of the third non-stabilized base layer

Layer 4 Non-stabilized Base : A-2-6

Unbound	
Layer thickness (in.)	9.0
Poisson's ratio	0.35
Coefficient of lateral earth pressure (k0)	0.5

Modulus (Input Level: 3)

Analysis Type:	Modify input values by temperature/moisture
Method:	Resilient Modulus (psi)

Resilient Modulus (psi)
26000.0

Use Correction factor for NDT modulus?	-
NDT Correction Factor:	-

Identifiers

Field	**Value**
Display name/identifier	A-2-6
Description of object	Default material
Author	AASHTO
Date Created	1/1/2011 12:00:00 AM
Approver	
Date approved	1/1/2011 12:00:00 AM
State	
District	
County	
Highway	
Direction of Travel	
From station (miles)	
To station (miles)	
Province	
User defined field 2	
User defined field 3	
Revision Number	0

Sieve

Liquid Limit	32.0
Plasticity Index	15.0
Is layer compacted?	False

	Is User Defined?	**Value**
Maximum dry unit weight (pcf)	False	121.9
Saturated hydraulic conductivity (ft/hr)	False	7.651e-06
Specific gravity of solids	False	2.7
Optimum gravimetric water content (%)	False	10

User-defined Soil Water Characteristic Curve (SWCC)	
Is User Defined?	False
af	75.5741
bf	0.9351
cf	0.4315
hr	500.0000

Sieve Size	**% Passing**
0.001mm	
0.002mm	
0.020mm	
#200	24.8
#100	
#80	32.4
#60	
#50	
#40	43.5
#30	
#20	
#16	
#10	59.4
#8	
#4	67.2
3/8-in.	78.8
1/2-in.	83.3
3/4-in.	90.4
1-in.	94.5
1 1/2-in.	97.7
2-in.	99.4
2 1/2-in.	
3-in.	
3 1/2-in.	99.9

Figure 7.20: Properties of the fourth non-stabilized base layer

Layer 5 Subgrade : A-4

Unbound	
Layer thickness (in.)	Semi-infinite
Poisson's ratio	0.35
Coefficient of lateral earth pressure (k0)	0.5

Modulus (Input Level: 3)

Analysis Type:	Modify input values by temperature/moisture
Method:	Resilient Modulus (psi)

Resilient Modulus (psi)
15000.0

Use Correction factor for NDT modulus?	-
NDT Correction Factor:	-

Identifiers

Field	**Value**
Display name/identifier	A-4
Description of object	Default material
Author	AASHTO
Date Created	1/1/2011 12:00:00 AM
Approver	
Date approved	1/1/2011 12:00:00 AM
State	
District	
County	
Highway	
Direction of Travel	
From station (miles)	
To station (miles)	
Province	
User defined field 2	
User defined field 3	
Revision Number	0

Sieve

Liquid Limit	21.0
Plasticity Index	5.0
Is layer compacted?	False

	Is User Defined?	**Value**
Maximum dry unit weight (pcf)	False	118.4
Saturated hydraulic conductivity (ft/hr)	False	8.325e-06
Specific gravity of solids	False	2.7
Optimum gravimetric water content (%)	False	11.8

User-defined Soil Water Characteristic Curve (SWCC)	
Is User Defined?	False
af	68.8377
bf	0.9983
cf	0.4757
hr	500.0000

Sieve Size	**% Passing**
0.001mm	
0.002mm	
0.020mm	
#200	60.6
#100	
#80	73.9
#60	
#50	
#40	82.7
#30	
#20	
#16	
#10	89.9
#8	
#4	93.0
3/8-in.	95.6
1/2-in.	96.7
3/4-in.	98.0
1-in.	98.7
1 1/2-in.	99.4
2-in.	99.6
2 1/2-in.	
3-in.	
3 1/2-in.	99.8

Figure 7.21: Properties of the subgrade layer

For District-1 lookout paving mixture, the first PCC layer information with PCC strength and modulus input level-l and level-3 is shown in Figure 7.22 and Figure 7.24, respectively. The summary of the design inputs and outputs for PCC strength and modulus input level 1 and 3 is shown in Figure 7.23 and Figure 7.25, respectively.

Layer Information

Layer 1 PCC : JPCP Default

PCC	
Thickness (in.)	9.0
Unit weight (pcf)	148.1
Poisson's ratio	0.1

Thermal	
PCC coefficient of thermal expansion (in./in./ºF x 10^-6)	3.75
PCC thermal conductivity (BTU/hr-ft-ºF)	1.25
PCC heat capacity (BTU/lb-ºF)	0.28

Mix		
Cement type		Type I (1)
Cementitious material content (lb/yd^3)		688
Water to cement ratio		0.35
Aggregate type		Limestone (1)
PCC zero-stress temperature (ºF)	Calculated Internally?	True
	User Value	-
	Calculated Value	77.7
Ultimate shrinkage (microstrain)	Calculated Internally?	True
	User Value	-
	Calculated Value	472.5
Reversible shrinkage (%)		50
Time to develop 50% of ultimate shrinkage (days)		35
Curing method		Wet Curing

PCC strength and modulus (Input Level: 1)

Time	Modulus of rupture (psi)	Elastic modulus (psi)
7-day	750	3850000
14-day	755	3900000
28-day	890	4150000
90-day	890	5150000
20-year/28-day	1.2	1.2

Identifiers

Field	Value
Display name/identifier	JPCP Default
Description of object	
Author	
Date Created	3/15/2017 3:22:51 PM
Approver	
Date approved	3/15/2017 3:22:51 PM
State	
District	
County	
Highway	
Direction of Travel	
From station (miles)	
To station (miles)	
Province	
User defined field 2	
User defined field 3	
Revision Number	0

Figure 7.22: Properties of the top PCC layer with PCC strength and modulus input level-l for District-1 lookout paving mixture

Design Inputs

Design Life:	30 years	Existing construction:	-	Climate Data Sources (Lat/Lon)	43.565, -116.22
Design Type:	Jointed Plain Concrete Pavement (JPCP)	Pavement construction:	April, 2017		
		Traffic opening:	May, 2017		

Design Structure

Layer type	Material Type	Thickness (in.):
PCC	JPCP Default	9.0
NonStabilized	A-1-a	4.4
NonStabilized	A-1-b	5.3
NonStabilized	A-2-6	9.0
Subgrade	A-4	Semi-infinite

Joint Design:	
Joint spacing (ft)	15.0
Dowel diameter (in.)	1.25
Slab width (ft)	12.0

Traffic

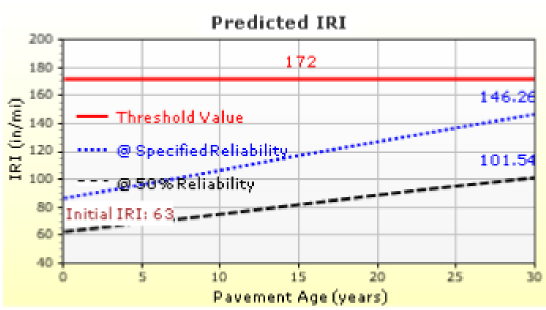
Age (year)	Heavy Trucks (cumulative)
2017 (initial)	2,449
2032 (15 years)	9,253,790
2047 (30 years)	21,949,100

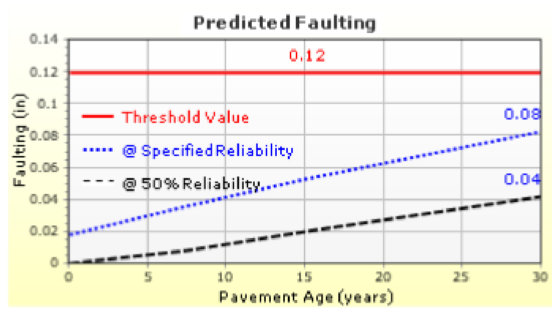
Design Outputs

Distress Prediction Summary

Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in./mile)	172.00	146.26	90.00	97.83	Pass
Mean joint faulting (in.)	0.12	0.08	90.00	99.33	Pass
JPCP transverse cracking (percent slabs)	15.00	4.49	90.00	100.00	Pass

Distress Charts





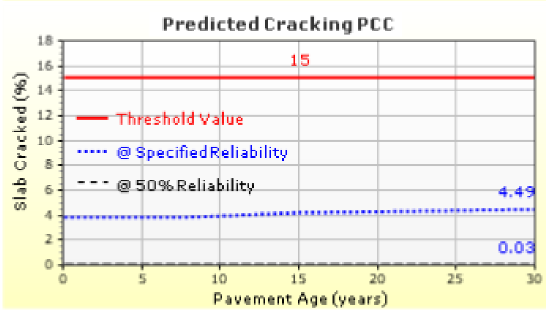


Figure 7.23: Summary of Inputs and Output for District-1 lookout paving mixtures using input level-1

Layer Information

Layer 1 PCC : JPCP Default

PCC	
Thickness (in.)	9.0
Unit weight (pcf)	148.1
Poisson's ratio	0.1

Thermal	
PCC coefficient of thermal expansion (in./in./ºF x 10^-6)	3.75
PCC thermal conductivity (BTU/hr-ft-ºF)	1.25
PCC heat capacity (BTU/lb-ºF)	0.28

Mix		
Cement type		Type I (1)
Cementitious material content (lb/yd^3)		688
Water to cement ratio		0.35
Aggregate type		Limestone (1)
PCC zero-stress temperature (ºF)	Calculated Internally?	True
	User Value	-
	Calculated Value	77.7
Ultimate shrinkage (microstrain)	Calculated Internally?	True
	User Value	-
	Calculated Value	500.7
Reversible shrinkage (%)		50
Time to develop 50% of ultimate shrinkage (days)		35
Curing method		Wet Curing

PCC strength and modulus (Input Level: 3)

28-Day PCC compressive strength (psi)	5510.0
28-Day PCC elastic modulus (psi)	895.0

Identifiers

Field	Value
Display name/identifier	JPCP Default
Description of object	
Author	
Date Created	3/15/2017 3:22:51 PM
Approver	
Date approved	3/15/2017 3:22:51 PM
State	
District	
County	
Highway	
Direction of Travel	
From station (miles)	
To station (miles)	
Province	
User defined field 2	
User defined field 3	
Revision Number	0

Figure 7.24: Properties of the top PCC layer with PCC strength and modulus input level-3 for District-1 lookout paving mixture

Design Inputs

Design Life: 30 years
Design Type: Jointed Plain Concrete Pavement (JPCP)

Existing construction: -
Pavement construction: April, 2017
Traffic opening: May, 2017

Climate Data Sources (Lat/Lon): 43.565, -116.22

Design Structure

Layer type	Material Type	Thickness (in.):
PCC	JPCP Default	9.0
NonStabilized	A-1-a	4.4
NonStabilized	A-1-b	5.3
NonStabilized	A-2-6	9.0
Subgrade	A-4	Semi-infinite

Joint Design:	
Joint spacing (ft)	15.0
Dowel diameter (in.)	1.25
Slab width (ft)	12.0

Traffic

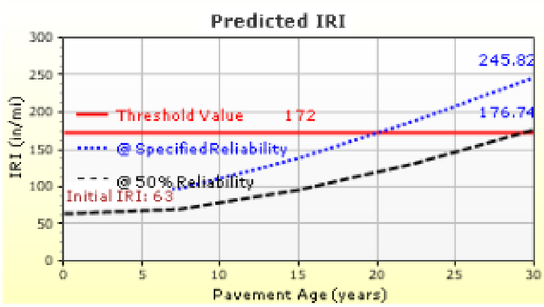
Age (year)	Heavy Trucks (cumulative)
2017 (initial)	2,449
2032 (15 years)	9,253,790
2047 (30 years)	21,949,100

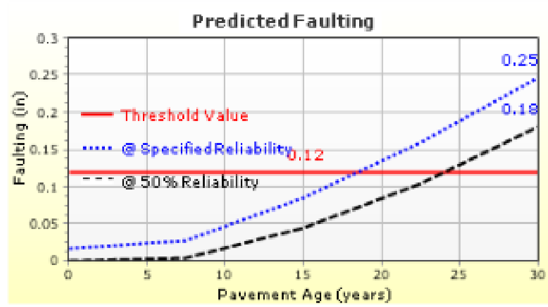
Design Outputs

Distress Prediction Summary

Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in./mile)	172.00	245.82	90.00	46.50	Fail
Mean joint faulting (in.)	0.12	0.25	90.00	11.74	Fail
JPCP transverse cracking (percent slabs)	15.00	3.83	90.00	100.00	Pass

Distress Charts





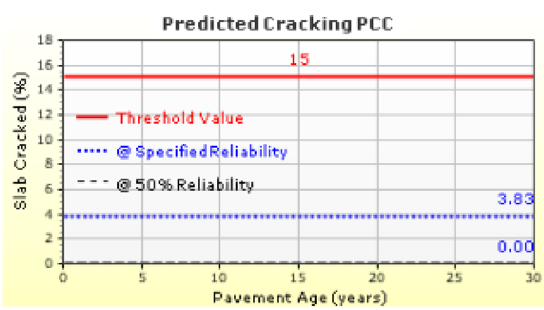


Figure 7.25: Summary of Inputs and Output for District-1 lookout paving mixtures using input level-3

Similarly, for District-2 Thain road paving mixture, the first PCC layer information with PCC strength and modulus input level-l and level-3 is shown in Figure 7.26 and Figure 7.28, respectively. The summary of the design inputs and outputs for PCC strength and modulus input level 1 and 3 is shown in Figure 7.27 and Figure 7.29, respectively.

Layer Information

Layer 1 PCC : JPCP Default

PCC	
Thickness (in.)	9.0
Unit weight (pcf)	144.7
Poisson's ratio	0.2

Thermal	
PCC coefficient of thermal expansion (in./in./ºF x 10^-6)	4.51
PCC thermal conductivity (BTU/hr-ft-ºF)	1.25
PCC heat capacity (BTU/lb-ºF)	0.28

Mix		
Cement type		Type I (1)
Cementitious material content (lb/yd^3)		611
Water to cement ratio		0.4
Aggregate type		Limestone (1)
PCC zero-stress temperature (ºF)	Calculated Internally?	True
	User Value	-
	Calculated Value	74.6
Ultimate shrinkage (microstrain)	Calculated Internally?	True
	User Value	-
	Calculated Value	494.1
Reversible shrinkage (%)		50
Time to develop 50% of ultimate shrinkage (days)		35
Curing method		Wet Curing

PCC strength and modulus (Input Level: 1)

Time	Modulus of rupture (psi)	Elastic modulus (psi)
7-day	595	3300000
14-day	660	3700000
28-day	785	3700000
90-day	865	4650000
20-year/28-day	1.2	1.2

Identifiers

Field	Value
Display name/identifier	JPCP Default
Description of object	
Author	
Date Created	3/15/2017 3:22:51 PM
Approver	
Date approved	3/15/2017 3:22:51 PM
State	
District	
County	
Highway	
Direction of Travel	
From station (miles)	
To station (miles)	
Province	
User defined field 2	
User defined field 3	
Revision Number	0

Figure 7.26: Properties of the top PCC layer with PCC strength and modulus input level-l for District-2 Thain road paving mixture

Design Inputs

Design Life: 30 years
Design Type: Jointed Plain Concrete Pavement (JPCP)

Existing construction: -
Pavement construction: April, 2017
Traffic opening: May, 2017

Climate Data Sources (Lat/Lon): 43.565, -116.22

Design Structure

Layer type	Material Type	Thickness (in.):
PCC	JPCP Default	9.0
NonStabilized	A-1-a	4.4
NonStabilized	A-1-b	5.3
NonStabilized	A-2-6	9.0
Subgrade	A-4	Semi-infinite

Joint Design:	
Joint spacing (ft)	15.0
Dowel diameter (in.)	1.25
Slab width (ft)	12.0

Traffic

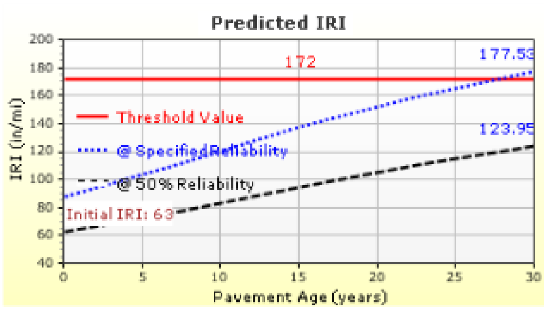
Age (year)	Heavy Trucks (cumulative)
2017 (initial)	2,449
2032 (15 years)	9,253,790
2047 (30 years)	21,949,100

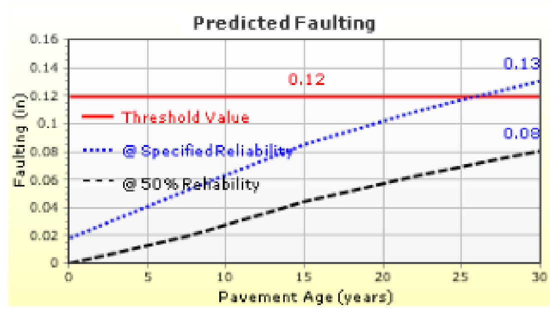
Design Outputs

Distress Prediction Summary

Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in./mile)	172.00	177.53	90.00	87.48	Fail
Mean joint faulting (in.)	0.12	0.13	90.00	83.83	Fail
JPCP transverse cracking (percent slabs)	15.00	6.42	90.00	99.92	Pass

Distress Charts





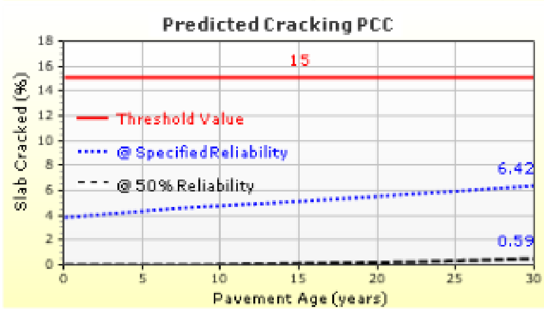


Figure 7.27: Summary of Inputs and Output for District-2 Thain road paving mixture using input level-1

Layer Information

Layer 1 PCC : JPCP Default

PCC		
Thickness (in.)		9.0
Unit weight (pcf)		144.7
Poisson's ratio		0.2

Thermal	
PCC coefficient of thermal expansion (in./in./°F x 10^-6)	4.51
PCC thermal conductivity (BTU/hr-ft-°F)	1.25
PCC heat capacity (BTU/lb-°F)	0.28

Mix		
Cement type		Type I (1)
Cementitious material content (lb/yd^3)		611
Water to cement ratio		0.4
Aggregate type		Limestone (1)
PCC zero-stress temperature (°F)	Calculated Internally?	True
	User Value	-
	Calculated Value	74.6
Ultimate shrinkage (microstrain)	Calculated Internally?	True
	User Value	-
	Calculated Value	512.4
Reversible shrinkage (%)		50
Time to develop 50% of ultimate shrinkage (days)		35
Curing method		Wet Curing

PCC strength and modulus (Input Level: 3)

28-Day PCC compressive strength (psi)	5160.0
28-Day PCC elastic modulus (psi)	3700000.0

Identifiers

Field	Value
Display name/identifier	JPCP Default
Description of object	
Author	
Date Created	3/15/2017 3:22:51 PM
Approver	
Date approved	3/15/2017 3:22:51 PM
State	
District	
County	
Highway	
Direction of Travel	
From station (miles)	
To station (miles)	
Province	
User defined field 2	
User defined field 3	
Revision Number	0

Figure 7.28: Properties of the top PCC layer with PCC strength and modulus input level-3 for District-2 Thain road paving mixture

Design Inputs

Design Life:	30 years	Existing construction:	-	Climate Data Sources (Lat/Lon)	43.565, -116.22
Design Type:	Jointed Plain Concrete Pavement (JPCP)	Pavement construction:	April, 2017		
		Traffic opening:	May, 2017		

Design Structure

Layer type	Material Type	Thickness (in.):
PCC	JPCP Default	9.0
NonStabilized	A-1-a	4.4
NonStabilized	A-1-b	5.3
NonStabilized	A-2-6	9.0
Subgrade	A-4	Semi-infinite

Joint Design:	
Joint spacing (ft)	15.0
Dowel diameter (in.)	1.25
Slab width (ft)	12.0

Traffic

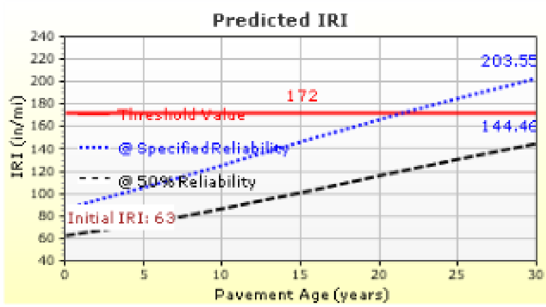
Age (year)	Heavy Trucks (cumulative)
2017 (initial)	2,449
2032 (15 years)	9,253,790
2047 (30 years)	21,949,100

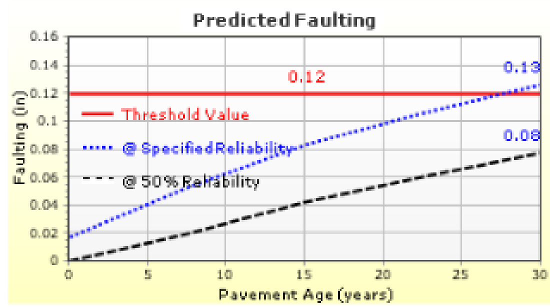
Design Outputs

Distress Prediction Summary

Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in./mile)	172.00	203.55	90.00	72.49	Fail
Mean joint faulting (in.)	0.12	0.13	90.00	86.75	Fail
JPCP transverse cracking (percent slabs)	15.00	38.43	90.00	13.46	Fail

Distress Charts





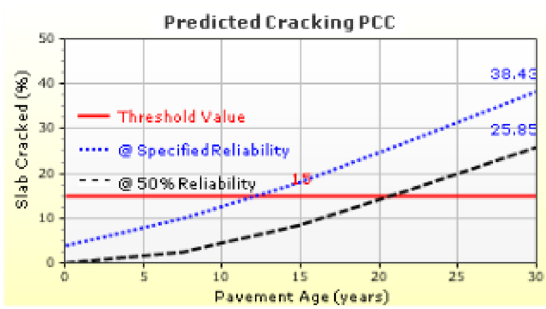


Figure 7.29: Summary of Inputs and Output for District-2 Thain road paving mixture using input level-3

Furthermore, for District-3 I-84 paving mixture, the first PCC layer information with PCC strength and modulus input level-l and level-3 is shown in Figure 7.30 and Figure 7.32, respectively. The summary of the design inputs and outputs for PCC strength and modulus input level 1 and 3 is shown in Figure 7.31 and Figure 7.33, respectively.

Layer Information

Layer 1 PCC : JPCP Default

PCC	
Thickness (in.)	9.0
Unit weight (pcf)	140.2
Poisson's ratio	0.2

Thermal	
PCC coefficient of thermal expansion (in./in./ºF x 10^-6)	5.08
PCC thermal conductivity (BTU/hr-ft-ºF)	1.25
PCC heat capacity (BTU/lb-ºF)	0.28

Mix		
Cement type		Type I (1)
Cementitious material content (lb/yd^3)		625
Water to cement ratio		0.36
Aggregate type		Limestone (1)
PCC zero-stress temperature (ºF)	Calculated Internally?	True
	User Value	-
	Calculated Value	75.1
Ultimate shrinkage (microstrain)	Calculated Internally?	True
	User Value	-
	Calculated Value	464.0
Reversible shrinkage (%)		50
Time to develop 50% of ultimate shrinkage (days)		35
Curing method		Wet Curing

PCC strength and modulus (Input Level: 1)

Time	Modulus of rupture (psi)	Elastic modulus (psi)
7-day	650	2750000
14-day	745	3200000
28-day	745	3600000
90-day	880	3800000
20-year/28-day	1.2	1.2

Identifiers

Field	Value
Display name/identifier	JPCP Default
Description of object	
Author	
Date Created	3/15/2017 3:22:51 PM
Approver	
Date approved	3/15/2017 3:22:51 PM
State	
District	
County	
Highway	
Direction of Travel	
From station (miles)	
To station (miles)	
Province	
User defined field 2	
User defined field 3	
Revision Number	0

Figure 7.30: Properties of the top PCC layer with PCC strength and modulus input level-l for District-3 I-84 paving mixture

Design Inputs

Design Life: 30 years
Design Type: Jointed Plain Concrete Pavement (JPCP)

Existing construction: -
Pavement construction: April, 2017
Traffic opening: May, 2017

Climate Data Sources (Lat/Lon): 43.565, -116.22

Design Structure

Layer type	Material Type	Thickness (in.):
PCC	JPCP Default	9.0
NonStabilized	A-1-a	4.4
NonStabilized	A-1-b	5.3
NonStabilized	A-2-6	9.0
Subgrade	A-4	Semi-infinite

Joint Design:	
Joint spacing (ft)	15.0
Dowel diameter (in.)	1.25
Slab width (ft)	12.0

Traffic

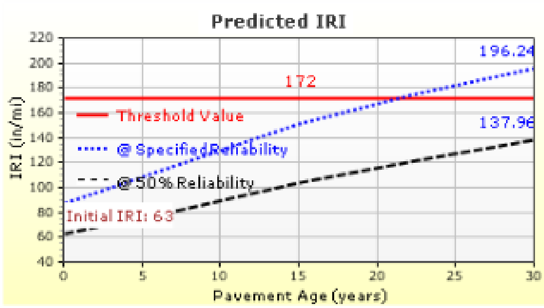
Age (year)	Heavy Trucks (cumulative)
2017 (initial)	2,449
2032 (15 years)	9,253,790
2047 (30 years)	21,949,100

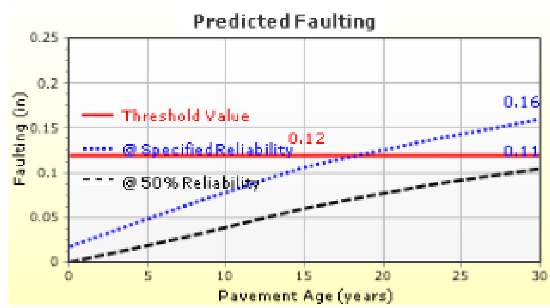
Design Outputs

Distress Prediction Summary

Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in./mile)	172.00	196.24	90.00	77.29	Fail
Mean joint faulting (in.)	0.12	0.16	90.00	62.85	Fail
JPCP transverse cracking (percent slabs)	15.00	8.35	90.00	99.45	Pass

Distress Charts





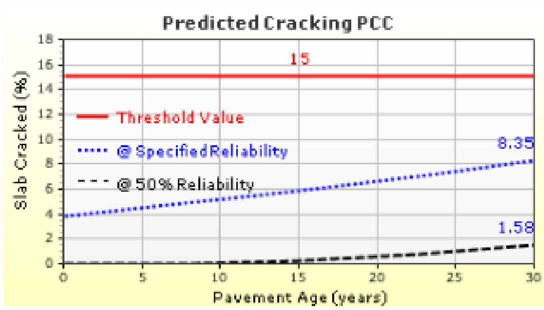


Figure 7.31: Summary of Inputs and Output for District-3 I-84 paving mixture using input level-1

Layer Information

Layer 1 PCC : JPCP Default

PCC	
Thickness (in.)	9.0
Unit weight (pcf)	140.2
Poisson's ratio	0.2

Thermal	
PCC coefficient of thermal expansion (in./in./ºF x 10^-6)	5.08
PCC thermal conductivity (BTU/hr-ft-ºF)	1.25
PCC heat capacity (BTU/lb-ºF)	0.28

Mix		
Cement type		Type I (1)
Cementitious material content (lb/yd^3)		625
Water to cement ratio		0.36
Aggregate type		Limestone (1)
PCC zero-stress temperature (ºF)	Calculated Internally?	True
	User Value	-
	Calculated Value	75.1
Ultimate shrinkage (microstrain)	Calculated Internally?	True
	User Value	-
	Calculated Value	469.3
Reversible shrinkage (%)		50
Time to develop 50% of ultimate shrinkage (days)		35
Curing method		Wet Curing

PCC strength and modulus (Input Level: 3)

28-Day PCC compressive strength (psi)	5590.0
28-Day PCC elastic modulus (psi)	3600000.0

Identifiers

Field	Value
Display name/identifier	JPCP Default
Description of object	
Author	
Date Created	3/15/2017 3:22:51 PM
Approver	
Date approved	3/15/2017 3:22:51 PM
State	
District	
County	
Highway	
Direction of Travel	
From station (miles)	
To station (miles)	
Province	
User defined field 2	
User defined field 3	
Revision Number	0

Figure 7.32: Properties of the top PCC layer with PCC strength and modulus input level-3 for District-3 I-84 paving mixture

Design Inputs

Design Life:	30 years	Existing construction:	-	Climate Data Sources (Lat/Lon)	43.565, -116.22
Design Type:	Jointed Plain Concrete Pavement (JPCP)	Pavement construction:	April, 2017		
		Traffic opening:	May, 2017		

Design Structure

Layer type	Material Type	Thickness (in.):
PCC	JPCP Default	9.0
NonStabilized	A-1-a	4.4
NonStabilized	A-1-b	5.3
NonStabilized	A-2-6	9.0
Subgrade	A-4	Semi-infinite

Joint Design:

Joint spacing (ft)	15.0
Dowel diameter (in.)	1.25
Slab width (ft)	12.0

Traffic

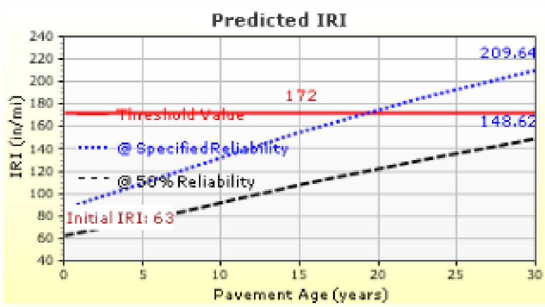
Age (year)	Heavy Trucks (cumulative)
2017 (initial)	2,449
2032 (15 years)	9,253,790
2047 (30 years)	21,949,100

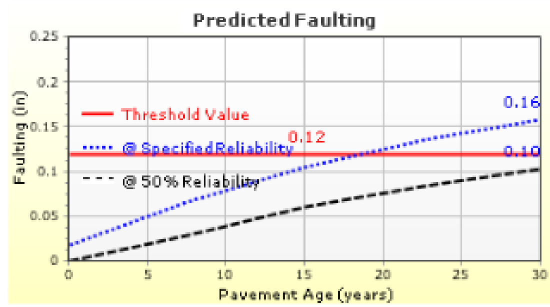
Design Outputs

Distress Prediction Summary

Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in./mile)	172.00	209.64	90.00	68.83	Fail
Mean joint faulting (in.)	0.12	0.16	90.00	64.34	Fail
JPCP transverse cracking (percent slabs)	15.00	25.72	90.00	50.75	Fail

Distress Charts





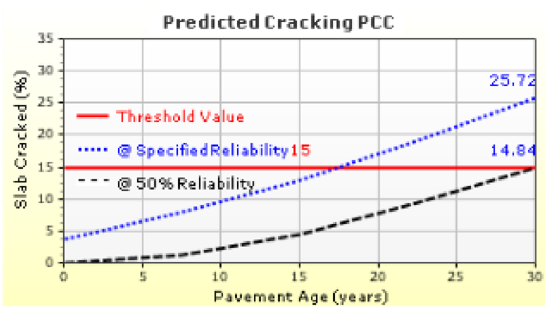


Figure 7.33: Summary of Inputs and Output for District-3 I-84 paving mixture using input level-3

Likewise, for District-5 US-90 paving mixture, the first PCC layer information with PCC strength and modulus input level-l and level-3 is shown in Figure 7.34 and Figure 7.36, respectively. The summary of the design inputs and outputs for PCC strength and modulus input level 1 and 3 is shown in Figure 7.35 and Figure 7.37, respectively.

Layer Information

Layer 1 PCC : JPCP Default

PCC	
Thickness (in.)	9.0
Unit weight (pcf)	140.2
Poisson's ratio	0.2

Thermal	
PCC coefficient of thermal expansion (in./in./ºF x 10^-6)	5.08
PCC thermal conductivity (BTU/hr-ft-ºF)	1.25
PCC heat capacity (BTU/lb-ºF)	0.28

Mix		
Cement type		Type I (1)
Cementitious material content (lb/yd^3)		729
Water to cement ratio		0.34
Aggregate type		Limestone (1)
PCC zero-stress temperature (ºF)	Calculated Internally?	True
	User Value	-
	Calculated Value	83
Ultimate shrinkage (microstrain)	Calculated Internally?	True
	User Value	-
	Calculated Value	502.5
Reversible shrinkage (%)		50
Time to develop 50% of ultimate shrinkage (days)		35
Curing method		Wet Curing

PCC strength and modulus (Input Level: 1)

Time	Modulus of rupture (psi)	Elastic modulus (psi)
7-day	655	4050000
14-day	730	4050000
28-day	775	4300000
90-day	790	4300000
20-year/28-day	1.2	1.2

Identifiers

Field	Value
Display name/identifier	JPCP Default
Description of object	
Author	
Date Created	3/15/2017 3:22:51 PM
Approver	
Date approved	3/15/2017 3:22:51 PM
State	
District	
County	
Highway	
Direction of Travel	
From station (miles)	
To station (miles)	
Province	
User defined field 2	
User defined field 3	
Revision Number	0

Figure 7.34: Properties of the top PCC layer with PCC strength and modulus input level-l for District-5 US-90 paving mixture

Design Inputs

Design Life:	30 years	Existing construction:	-	Climate Data Sources (Lat/Lon)	43.565, -116.22
Design Type:	Jointed Plain Concrete Pavement (JPCP)	Pavement construction:	October, 2010		
		Traffic opening:	December, 2010		

Design Structure

Layer type	Material Type	Thickness (in.):
PCC	JPCP Default	9.0
NonStabilized	A-1-a	4.4
NonStabilized	A-1-b	5.3
NonStabilized	A-2-6	9.0
Subgrade	A-4	Semi-infinite

Joint Design:	
Joint spacing (ft)	15.0
Dowel diameter (in.)	1.25
Slab width (ft)	12.0

Traffic

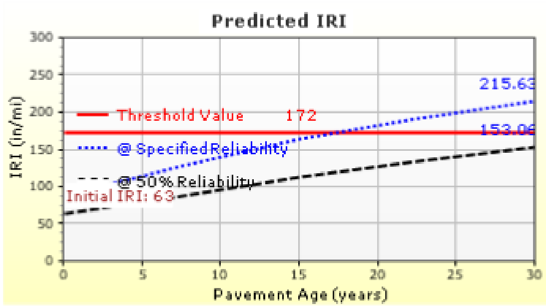
Age (year)	Heavy Trucks (cumulative)
2010 (initial)	2,449
2025 (15 years)	9,253,790
2040 (30 years)	21,949,100

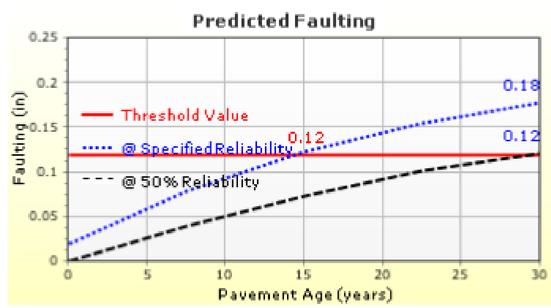
Design Outputs

Distress Prediction Summary

Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in./mile)	172.00	215.63	90.00	65.10	Fail
Mean joint faulting (in.)	0.12	0.18	90.00	49.01	Fail
JPCP transverse cracking (percent slabs)	15.00	20.40	90.00	72.15	Fail

Distress Charts





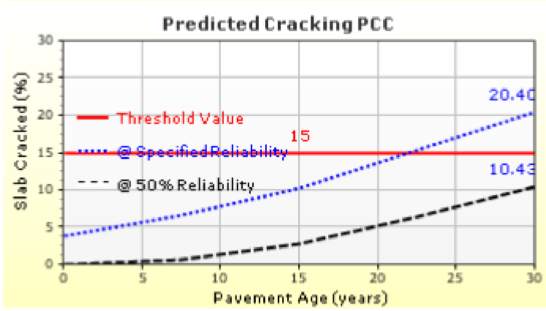


Figure 7.35: Summary of Inputs and Output for District-5 US-90 paving mixture using input level-1

Layer Information

Layer 1 PCC : JPCP Default

PCC	
Thickness (in.)	9.0
Unit weight (pcf)	140.2
Poisson's ratio	0.2

Thermal	
PCC coefficient of thermal expansion (in./in./ºF x 10^-6)	5.08
PCC thermal conductivity (BTU/hr-ft-ºF)	1.25
PCC heat capacity (BTU/lb-ºF)	0.28

Mix		
Cement type		Type I (1)
Cementitious material content (lb/yd^3)		729
Water to cement ratio		0.34
Aggregate type		Limestone (1)
PCC zero-stress temperature (ºF)	Calculated Internally?	True
	User Value	-
	Calculated Value	83
Ultimate shrinkage (microstrain)	Calculated Internally?	True
	User Value	-
	Calculated Value	520.8
Reversible shrinkage (%)		50
Time to develop 50% of ultimate shrinkage (days)		35
Curing method		Wet Curing

PCC strength and modulus (Input Level: 3)

28-Day PCC compressive strength (psi)	5080.0
28-Day PCC elastic modulus (psi)	4300000.0

Identifiers

Field	Value
Display name/identifier	JPCP Default
Description of object	
Author	
Date Created	3/15/2017 3:22:51 PM
Approver	
Date approved	3/15/2017 3:22:51 PM
State	
District	
County	
Highway	
Direction of Travel	
From station (miles)	
To station (miles)	
Province	
User defined field 2	
User defined field 3	
Revision Number	0

Figure 7.36: Properties of the top PCC layer with PCC strength and modulus input level-3 for District-5 US-90 paving mixture

Design Inputs

Design Life:	30 years	Existing construction:	-	Climate Data Sources (Lat/Lon)	43.565, -116.22
Design Type:	Jointed Plain Concrete Pavement (JPCP)	Pavement construction:	October, 2010		
		Traffic opening:	December, 2010		

Design Structure

Layer type	Material Type	Thickness (in.):
PCC	JPCP Default	9.0
NonStabilized	A-1-a	4.4
NonStabilized	A-1-b	5.3
NonStabilized	A-2-6	9.0
Subgrade	A-4	Semi-infinite

Joint Design:	
Joint spacing (ft)	15.0
Dowel diameter (in.)	1.25
Slab width (ft)	12.0

Traffic

Age (year)	Heavy Trucks (cumulative)
2010 (initial)	2,449
2025 (15 years)	9,253,790
2040 (30 years)	21,949,100

Design Outputs

Distress Prediction Summary

Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in./mile)	172.00	288.16	90.00	23.76	Fail
Mean joint faulting (in.)	0.12	0.18	90.00	46.27	Fail
JPCP transverse cracking (percent slabs)	15.00	97.52	90.00	0.00	Fail

Distress Charts

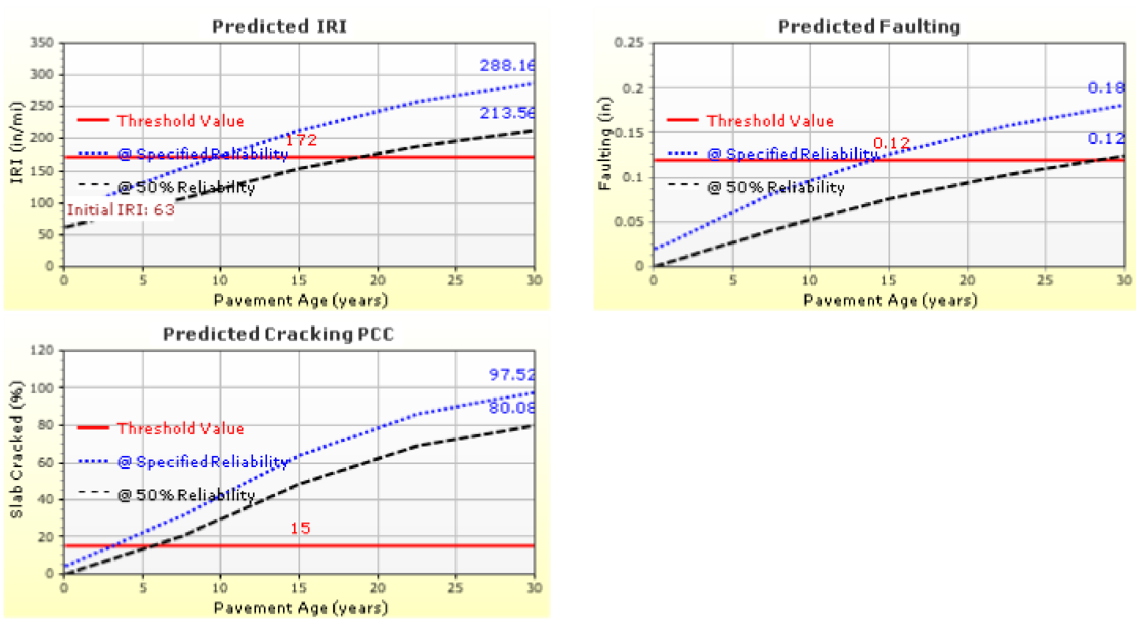


Figure 7.37: Summary of Inputs and Output for District-5 US-90 paving mixture using input level-3

7.8 SUMMARY AND CONCLUSION

The mechanical, thermal and durability properties were evaluated for a total of six mixtures from 4 highway districts in the State of Idaho. These properties were used to establish a material input database to implement in AASHTOWare Pavement ME Design software. The

4 districts include District 1 (two mixtures), District 2 (two mixtures), District 3 and District 5. The two mixtures M1 and M2 from District 1 were used as Structural mixtures and in Lookout paving project (I-90 Mullan to Montana State Line), respectively. The two mixtures M3 and M4 from District 2 were the Thain Road paving mixture and the US-95 Race Creek Bridge structural mixture. District 3 provided the I-84 Paving Mixture and for District 5, the US-90 Paving Mixture.

The Washington State University (WSU) has requested an additional quantity of aggregate from District 1 and correspondence with the representative from District 4 and 6 will be continued to acquire materials from these two districts. The PCC material input database is currently under development and in a trial phase. Time-dependent properties – drying shrinkage and CTE – are still being evaluated. The results of these additional tests will be used to update the database. After completion and approval from the users, the PCC material input database will be combined with the current ME database for implementation in ME design software.

The successful implementation of the PCC materials database onto AASHTOWare Pavement ME Design software to design a rigid pavement (JPCP) and predict the performance of the given section is presented here. The difference in the performance predication due to the use of Level 1 and Level 3 data are clearly visible in the results. After establishing all input level PCC characteristics database for the six highway districts of State of Idaho, design engineers now can use AASHTOWare Pavement ME Design software to design a rigid pavement in Idaho State.

REFERENCES

[1] E. Aprianti S, “A huge number of artificial waste material can be supplementary cementitious material (SCM) for concrete production – a review part II,” *J. Clean. Prod.*, vol. 142, pp. 4178–4194, Jan. 2017.

[2] A. Ibrahim, H. El-Chabib, and A. Eisa, “Ultrastrength Flowable Concrete Made with High Volumes of Supplementary Cementitious Materials,” *J. Mater. Civ. Eng.*, vol. 25, no. 12, pp. 1830–1839, Dec. 2013.

[3] EFNARC, “The European Guidelines for Self-Compacting Concrete: Specification, Production and Use,” *Eur. Guidel. Self Compact. Concr.*, 2005.

[4] ACI-237R, “7 Self-Consolidating Concrete,” *Am. Concr. Inst. Farmingt. Hills, MI, USA*, pp. 1–34, 2007.

[5] F. Aslani and S. Nejadi, “Self-compacting concrete incorporating steel and polypropylene fibers: Compressive and tensile strengths, moduli of elasticity and rupture, compressive stress-strain curve, and energy dissipated under compression,” *Compos. Part B Eng.*, vol. 53, pp. 121–133, 2013.

[6] G. Jen, W. Trono, and C. P. Ostertag, “Self-consolidating hybrid fiber reinforced concrete: Development, properties and composite behavior,” *Constr. Build. Mater.*, vol. 104, pp. 63–71, Feb. 2016.

[7] K. M. A. Hossain, M. Lachemi, M. Sammour, and M. Sonebi, “Strength and fracture energy characteristics of self-consolidating concrete incorporating polyvinyl alcohol, steel and hybrid fibres,” *Constr. Build. Mater.*, vol. 45, pp. 20–29, 2013.

[8] A. Fathi, M. Salih, N. Shafiq, M. F. Nuruddin, and A. Elheber, “Performance of Fiber Reinforced Self-Compacting Concrete Containing Different Pozzolanic Material : State of the Art,” vol. 1, no. 1, pp. 22–27, 2014.

[9] M. Ouchi *et al.*, “APPLICATIONS OF SELF-COMPACTING CONCRETE IN JAPAN, EUROPE AND THE UNITED STATES,” *Fed. Highw. Adm.*, 2003.

[10] L. A. Mata., “Implementation of Self-consolidating Concrete for Prestressed Concrete Girders,” *Dep. Civil, Constr. Environ. Eng. North Carolina State Univ. Raleigh, N.C. 27695-7908*, vol. Report, no., p. 82, 2004.

[11] K. H. Khayat, “Workability, Testing, and Performance of Self-Consolidating Concrete,” *ACI Mater. J.*, vol. 96, no. 3, pp. 339–346, 1999.

[12] K. H. Khayat, P. Paultre, and S. Tremblay, “Structural Performance and In-Place Properties of Self-Consolidating Concrete Used for Casting Highly Reinforced Columns,” *ACI Mater. J.*, vol. 98, no. 5, 2001.

[13] Y.-W. Chan, Y.-S. Chen, and Y.-S. Liu, “Development of Bond Strength of Reinforcement Steel in Self-Consolidating Concrete,” *ACI Struct. J.*, vol. 100, no. 4, 2003.

[14] PCI Fast Team, *Interim Guidelines for the Use of Self-Consolidating Concrete in Precast/Prestressed Concrete Institute Member Plants*. 2003.

[15] ASTM Sub-Committee C09.47, “Chapter 56: Self-Consolidating Concrete (SCC),” in *Significance of Tests and Properties of Concrete and Concrete-Making Materials*, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959: ASTM International, 2006, pp. 637-637–9.

[16] K. H. Khayat, J. J. Assaad, and J. Daczko, “Comparison of Field- Oriented Test Methods to Assess Dynamic Stability of Self-Consolidating Concrete,” *ACI Mater. J.*, vol. 101, no. 2, pp. 168–176, 2004.

[17] J. Assad, K. H. Khayat, and H. Mesbah, “Assessment of Thixotropy of Flowable and Self-Compacting Concrete,” *ACI Mater. J.*, vol. 100, no. 2, pp. 99–107, 2003.

[18] M. Sonebi, A. K. Tamimi, and P. J. M. Bartos, “Performance and Cracking Behavior of Reinforced Beams Cast with Self-Consolidating Concrete,” *ACI Mater. J.*, vol. 100, no. 6, pp. 492–500, 2003.

[19] A. Jansson, I. Löfgren, and K. Gylltoft, “Design methods for fibre-reinforced concrete : a state-of-the-art review,” *Submitt. to Nord. Concr. Res.*, 2008.

[20] ACI Committee 544, “State-of-the-Art Report on Fiber Reinforced Concrete,” in *ACI 544.1R- 96*, vol. 70, no. 11, 2002, p. 66.

[21] L. Ferrara, P. Bamonte, A. Caverzan, A. Musa, and I. Sanal, “A comprehensive methodology to test the performance of Steel Fibre Reinforced Self-Compacting Concrete (SFR-SCC),” *Constr. Build. Mater.*, vol. 37, pp. 406–424, Dec. 2012.

[22] R. Deeb, A. Ghanbari, and B. L. Karihaloo, “Development of self-compacting high and ultra high performance concretes with and without steel fibres,” *Cem. Concr. Compos.*, vol. 34, no. 2, pp. 185–190, Feb. 2012.

[23] K. M. A. Hossain, M. Lachemi, M. Sammour, and M. Sonebi, “Influence of Polyvinyl Alcohol, Steel, and Hybrid Fibers on Fresh and Rheological Properties of Self-Consolidating Concrete,” *ASCE J. Mater. Civ. Eng.*, vol. 24, no. 9, pp. 1211–1220, Sep. 2012.

[24] S. Ahmad, A. K. Azad, M. A. Hameed, and S. Arabia, “a Study of Self-Compacting Concrete Made With Marginal Aggregates,” *Arab. J. Sci. Eng.*, vol. 33, no. 2, pp. 437–442, 2008.

[25] ASTM, “ASTM C150 / C150M - 09 Standard Specification for Portland Cement,” 2009.

[26] B. C. Gerwick and Jr., *Construction of Prestressed Concrete Structures*. Wiley, 1997.

[27] N. Bouzoubaâ and M. Lachemi, “Self-compacting concrete incorporating high volumes of class F fly ash: Preliminary results,” *Cem. Concr. Res.*, vol. 31, no. 3, pp. 413–420, Mar. 2001.

[28] V. Cervantes and J. Roesler, “Furnace, Ground Granulated Blast Slag,” *Cent. Excell. Airpt. Technol.*, no. 325, pp. 4–7, 2007.

[29] M. Lachemi, K. M. A. Hossain, V. Lambros, and N. Bouzoubaa, “Development of Cost-Effective Self-Consolidating Concrete Incorporating Fly Ash, Slag Cement, or\r\nViscosity-Modifying Admixtures,” *Mater. J.*, vol. 100, no. 5, pp. 419–425, 2003.

[30] H. G. Russell, *High-Performance Concrete--From Buildings to Bridges*, vol. 19, no. 8. The Institute, 1997.

[31] K. Sobolev and S. Soboleva, “92+ GRADE HIGH PERFORMANCE CEMENT: SOLUTION FOR NEXT MILLENNIUM,” 1999.

[32] C. Ozyildirim, “Performance of First Structure Built with High-Performance Concrete in Virginia,” *Transp. Res. Rec.*, vol. 1798, no. 1, pp. 43–50, Jan. 2002.

[33] ASTM C618, *Standard specification for coal fly ash and raw or calcined natural pozzolona for use in concrete*. 2015.

[34] P. K. Mehta, “High-performance, high-volume fly ash concrete for sustainable development,” *Int. Work. Sustain. Dev. Concr. Technol.*, pp. 3–14, 2004.

[35] T. R. Naik and S. S. Singh, “Influence of Fly Ash on Setting and Hardening Characteristics of Concrete Systems,” *ACI Mater. J.*, vol. 94, no. 5, 1997.

[36] ACI, *ACI CT-13. ACI Concrete terminology*. 2013, p. 78.

[37] S. Lambot, E. C. Slob, I. Den Van Bosch, B. Stockbroeckx, and M. Vanclooster, “Modeling of ground-penetrating radar for accurate characterization of subsurface electric properties,” *IEEE Trans. Geosci. Remote Sens.*, vol. 42, no. 11, pp. 2555–2568, 2004.

[38] J. K. Su, S. W. Cho, C. C. Yang, and R. Huang, “Effect of sand ratio on the elastic modulus of self-compacting concrete,” *J. Mar. Sci. Technol.*, vol. 10, no. 1, pp. 8–13, 2002.

[39] V. K. Bui, Y. Akkaya, and S. P. Shah, “Rheological model for self-consolidating concrete,” *ACI Mater. J.*, vol. 99, no. 6, pp. 549–559, 2002.

[40] ACI 116R, *Cement and Concrete Terminology(Reapproved 2005)*. 2000.

[41] ACI Committee 212. and American Concrete Institute., *Report on Chemical Admixtures for Concrete*. American Concrete, 2016.

[42] ACI Committee E701, “E4-12 Chemical Admixtures for Concrete,” 2012.

[43] C. F. Ferraris, "Measurement of the rheological properties of high performance concrete: State of the art report," *J. Res. Natl. Inst. Stand. Technol.*, vol. 104, no. 5, p. 461, 1999.

[44] H. El Chabib and A. Syed, "Properties of Self-Consolidating Concrete Made with High Volumes of Supplementary Cementitious Materials," *J. Mater. Civ. Eng.*, vol. 25, no. 309, p. 121112054517008, Nov. 2012.

[45] ASTM C39, "ASTM C39 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens," in *ASTM Standard Book*, 2016, pp. 1–5.

[46] M. Peterson, *High-performance and self-compacting concrete in house building Field tests and theoretical studies of possibilities and difficulties*. 2008.

[47] Y. Xie, B. Liu, J. Yin, and S. Zhou, "Optimum mix parameters of high-strength self-compacting concrete with ultrapulverized fly ash," *Cem. Concr. Res.*, vol. 32, no. 3, pp. 477–480, Mar. 2002.

[48] A. Leemann and C. Hoffmann, "Properties of self-compacting and conventional concrete – differences and similarities," *Mag. Concr. Res.*, vol. 57, no. 6, pp. 315–319, Aug. 2005.

[49] ASTM C469 / C469M-14, "ASTM C469 / C469M-14, Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression," 2014.

[50] Y. P. K. C. M. and K. Charif, "Self Compacting Concrete An Economical Approach," *7th Int. Conf. Concr. Hot Aggress. Env.*, no. October, pp. 509–520, 2003.

[51] ASTM C150/C150M, "Standard Specification for Portland Cement," 2016.

[52] ASTM-C127-15.2, "Standard Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregate - ASTM Subcommittee C09.20," *ASTM Int.*, p. 5, 2015.

[53] ASTM C128, "Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate," *ASTM Int.*, vol. i, p. 6, 2015.

[54] ASTM C192/C192M, “Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory,” *Am. Soc. Test. Mater.*, pp. 1–8, 2016.

[55] ASTM C 490, “Standard Practice for Use of Apparatus for the Determination of Length Change of Hardened Cement Paste , Mortar , and Concrete,” *Annu. B. ASTM Stand.*, no. C, pp. 1–5, 2011.

[56] ASTM C1611, “ASTM C1611 / C1611M - 2009 Standard Test Method for Slump Flow of Self-Consolidating Concrete,” in *ASTM International, West Conshohocken, PA*, 2009.

[57] ASTM C1621, “C 1621M-09b ‘Standard Test Method for Passing Ability of Self-Consolidating Concrete by J-Ring,’” *Annu. B. ASTM Stand.*, vol. i, p. 5, 2014.

[58] ASTM C496/C496M, “Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens,” *Am. Soc. Test. Mater.*, pp. 1–5, 2011.

[59] ITD, “Standard Specifications for Highway Construction,” 2012.

[60] ASTM C 143, “ASTM C143 / C143M - 08: Standard Test Method for Slump of Hydraulic-Cement Concrete,” 2008.

[61] ASTM C231 / C231M, “Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method.” 2014.

[62] ASTM C138/C138M-13, “Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric),” *ASTM Int.*, vol. i, pp. 23–26, 2013.

[63] ASTM C511, “Standard Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes,” 2013.

[64] ASTM C31 / C31M, “Standard Practice for Making and Curing Concrete Test Specimens in the Field,” *ASTM International, West Conshohocken*, 2015. [Online]. Available: https://www.astm.org/Standards/C31.htm. [Accessed: 19-Mar-2017].

[65] ASTM C293 / C293M, “Standard Test Method for Flexural Strength of Concrete (Using Simple Beam With Center-Point Loading),” 2016.

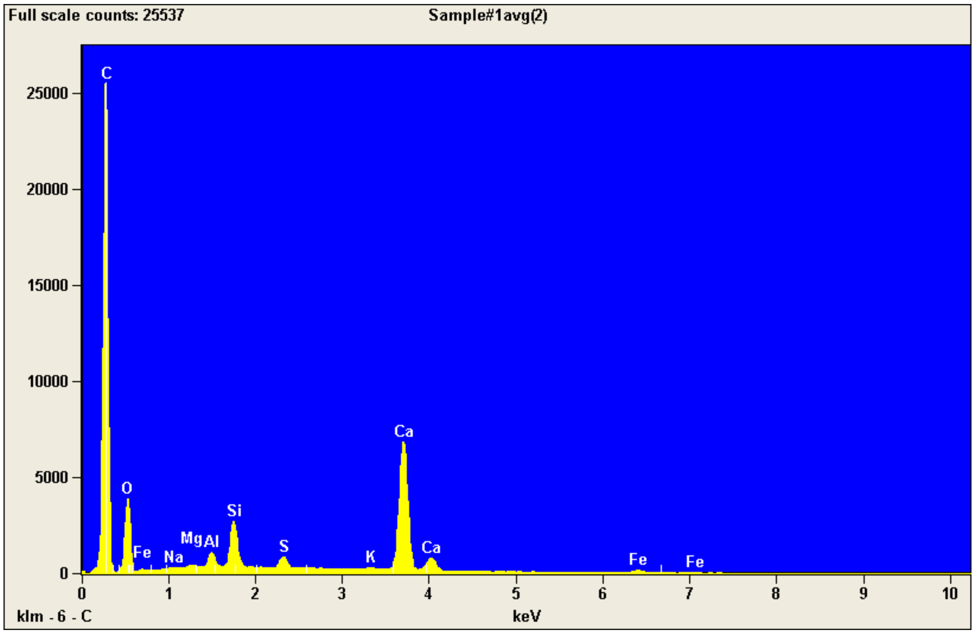
[66] AASHTO T 336-15, “Standard Method of Test for Coefficient of Thermal Expansion of Hydraulic Cement Concrete,” 2015.

[67] ASTM C157, “StandardTest Method for Length Change of Hardened Hydraulic-Cement Mortar and,” *Annu. B. ASTM Stand.*, no. c, pp. 1–7, 2016.

APPENDICES

APPENDIX-A: SCANNING ELECTRON MICROSCOPY / ENERGY DISPERSIVE X-RAY SPECTROSCOPY (SEM/EDS) ANALYSIS RESULTS

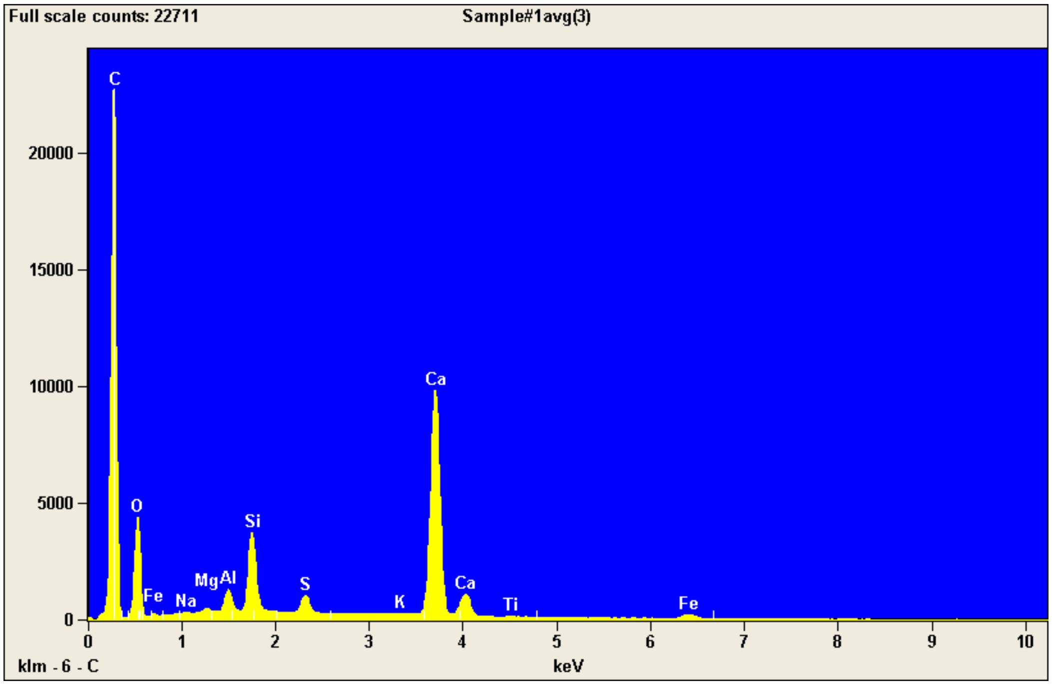
Sample #1= Type I Cement; Sample #2=Silica Fume; Sample #3=Ground Granulated Blast Furnace Slag; Sample #4=Fly Ash



Live Time: 100.0 sec.

Quantitative Results for: Sample#1avg(2)

Element Line	*Net Counts*	*Net Counts Error*	*Weight %*	*Weight % Error*	*Atom %*	*Atom % Error*
O K	25412	+/- 524	57.71	+/- 0.60	75.64	+/- 1.56
Na K	599	+/- 180	0.40	+/- 0.06	0.37	+/- 0.11
Mg K	947	+/- 346	0.41	+/- 0.08	0.35	+/- 0.13
Al K	5926	+/- 258	1.92	+/- 0.04	1.49	+/- 0.06
Si K	22267	+/- 356	6.40	+/- 0.05	4.78	+/- 0.08
S K	6986	+/- 482	1.74	+/- 0.06	1.14	+/- 0.08
K K	1011	+/- 214	0.31	+/- 0.03	0.17	+/- 0.04
Ca K	84877	+/- 1050	29.68	+/- 0.18	15.53	+/- 0.19
Fe K	1659	+/- 428	1.42	+/- 0.18	0.53	+/- 0.14
Total			100.00		100.00	



Live Time: 100.0 sec.

Quantitative Results for: Sample#1avg(3)

Element Line	*Net Counts*	*Net Counts Error*	*Weight %*	*Weight % Error*	*Atom %*	*Atom % Error*
O K	28176	+/- 522	53.53	+/- 0.50	72.53	+/- 1.34
Na K	774	+/- 180	0.40	+/- 0.05	0.38	+/- 0.09
Mg K	1299	+/- 202	0.43	+/- 0.03	0.39	+/- 0.06
Al K	7658	+/- 268	1.91	+/- 0.03	1.53	+/- 0.05
Si K	31787	+/- 418	7.01	+/- 0.05	5.41	+/- 0.07
S K	8669	+/- 304	1.67	+/- 0.03	1.13	+/- 0.04
K K	1156	+/- 226	0.27	+/- 0.03	0.15	+/- 0.03
Ca K	121268	+/- 1310	32.55	+/- 0.18	17.61	+/- 0.19
Ti K	537	+/- 180	0.23	+/- 0.04	0.10	+/- 0.03
Fe K	3041	+/- 252	2.00	+/- 0.08	0.78	+/- 0.06
Total			100.00		100.00	

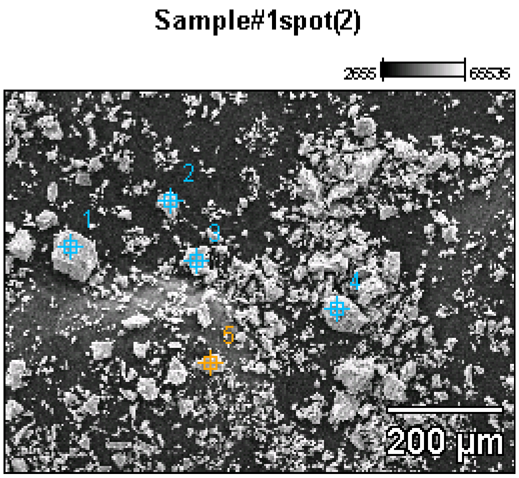
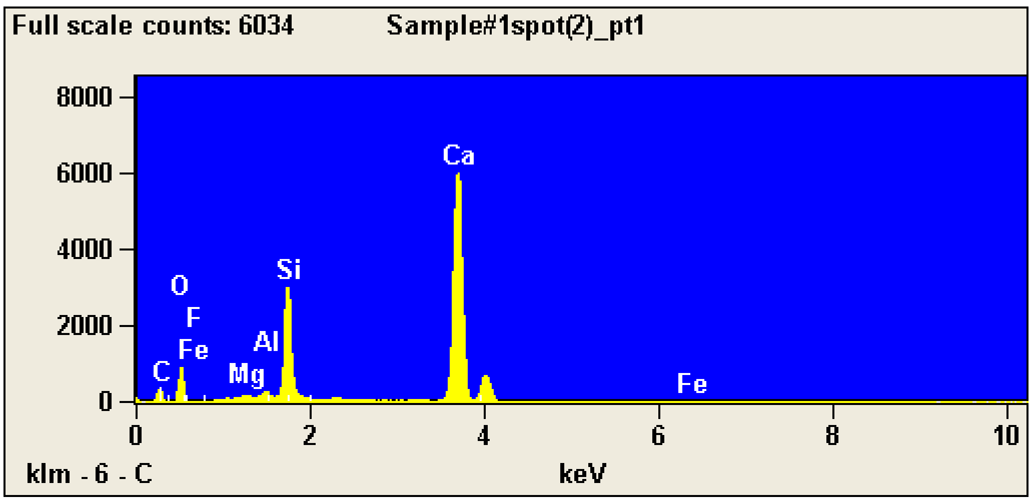
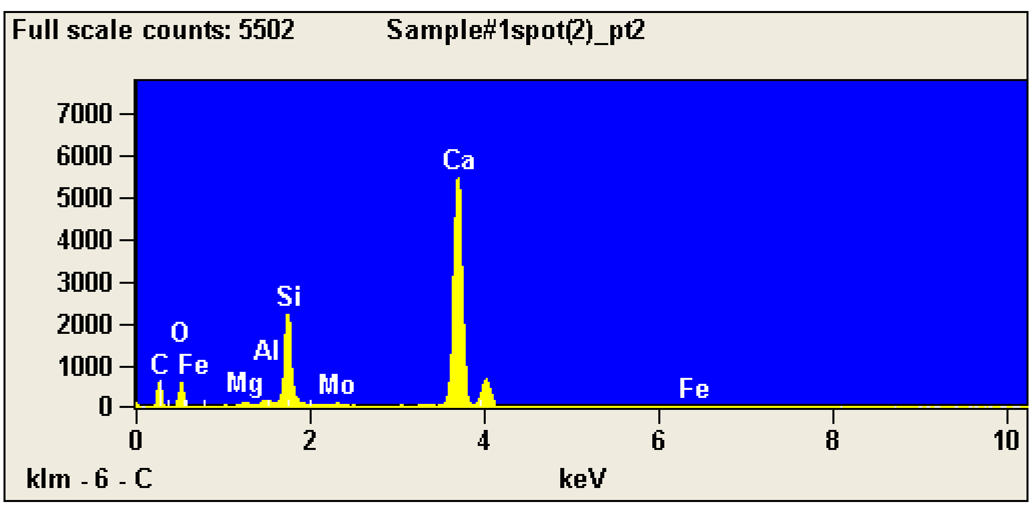


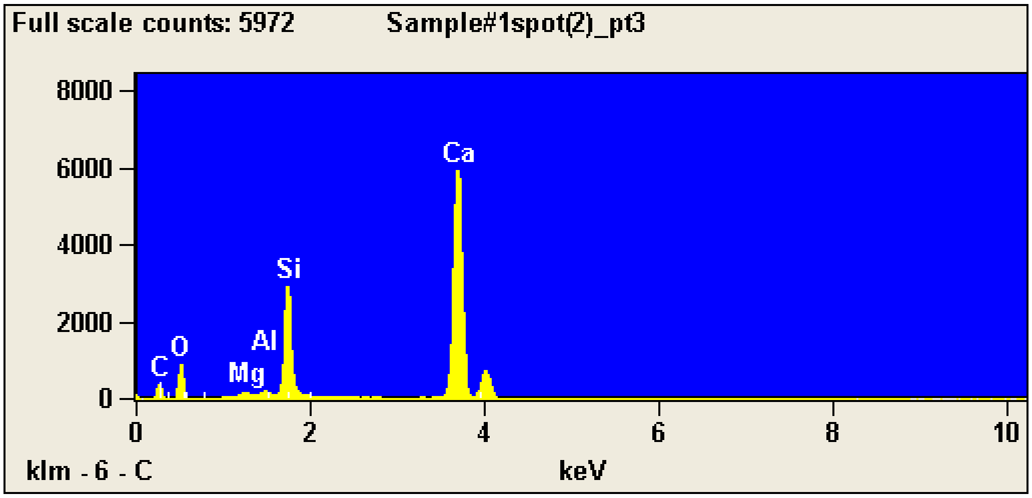
Image Name: Sample#1spot(2)

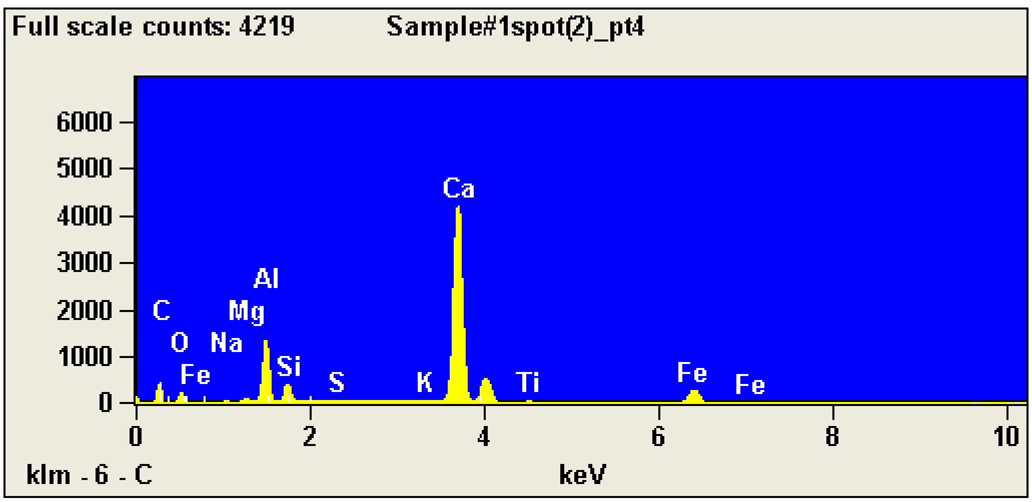
Accelerating Voltage: 20.0 kV

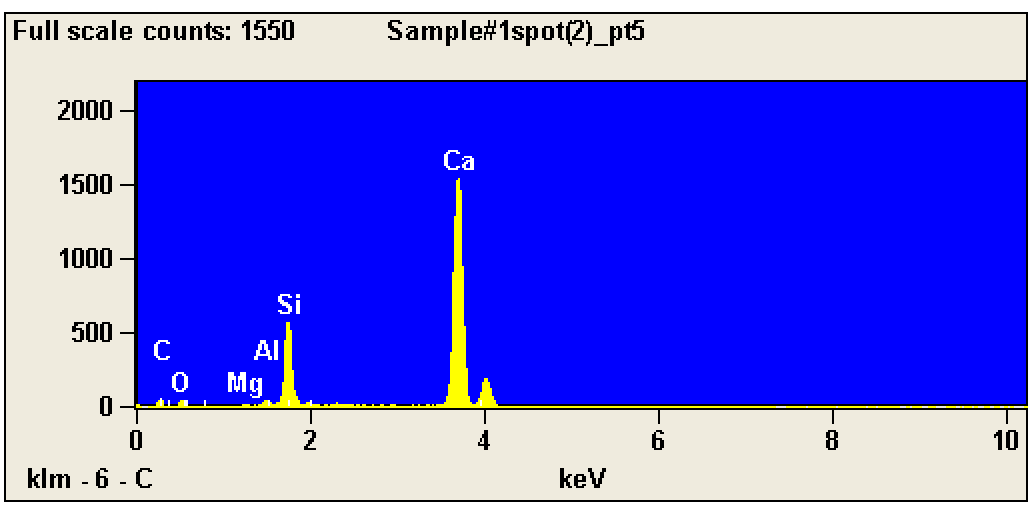
Magnification: 135

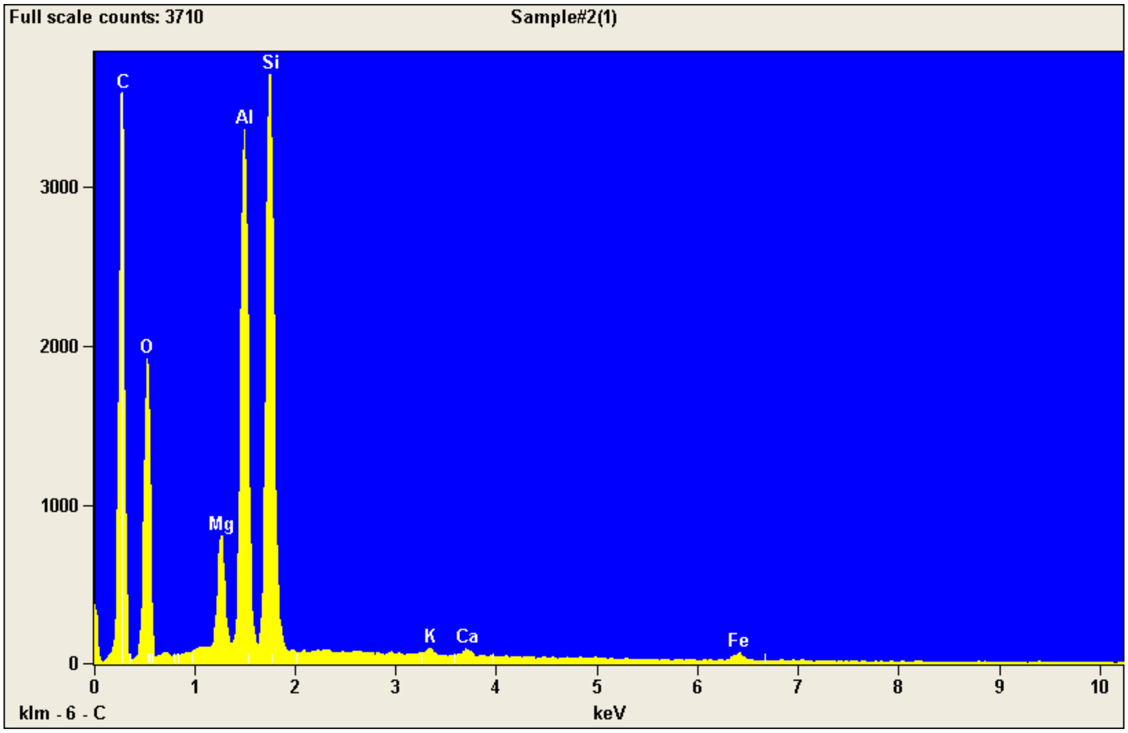





Full scale counts: 5972
Sample#1spot(2)_pt3
8000
6000
4000
2000
0
Ca
Si
O
C
Al
Mg
0
2
4
6
8
10
klm - 6 - C
keV


Full scale counts: 4219
Sample#1spot(2)_pt4
6000
5000
4000
3000
2000
1000
0
Ca
Al
C
Mg
O
Na
Fe
Si
S
K
Ti
Fe
Fe
0
2
4
6
8
10
klm - 6 - C
keV

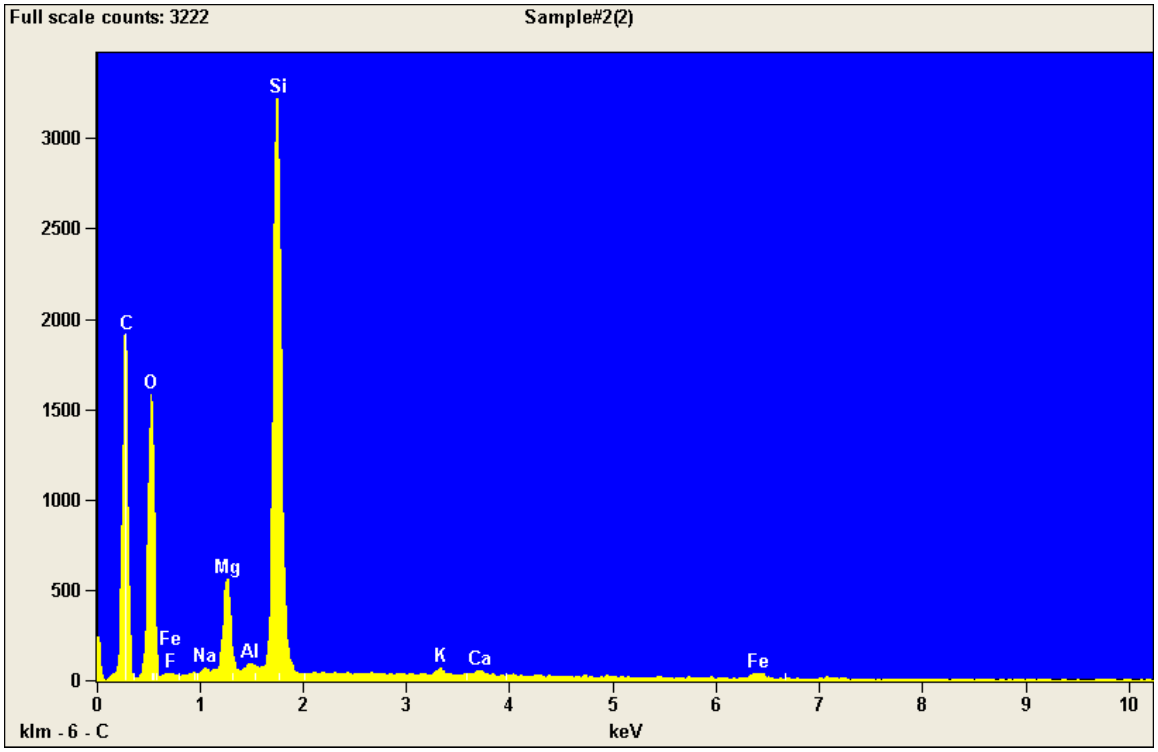

Full scale counts: 1550
Sample#1spot(2)_pt5
2000
1500
1000
500
0
Ca
Si
C
Al
O
Mg
0
2
4
6
8
10
klm - 6 - C
keV



Live Time: 100.0 sec.

Quantitative Results for: Sample#2(1)

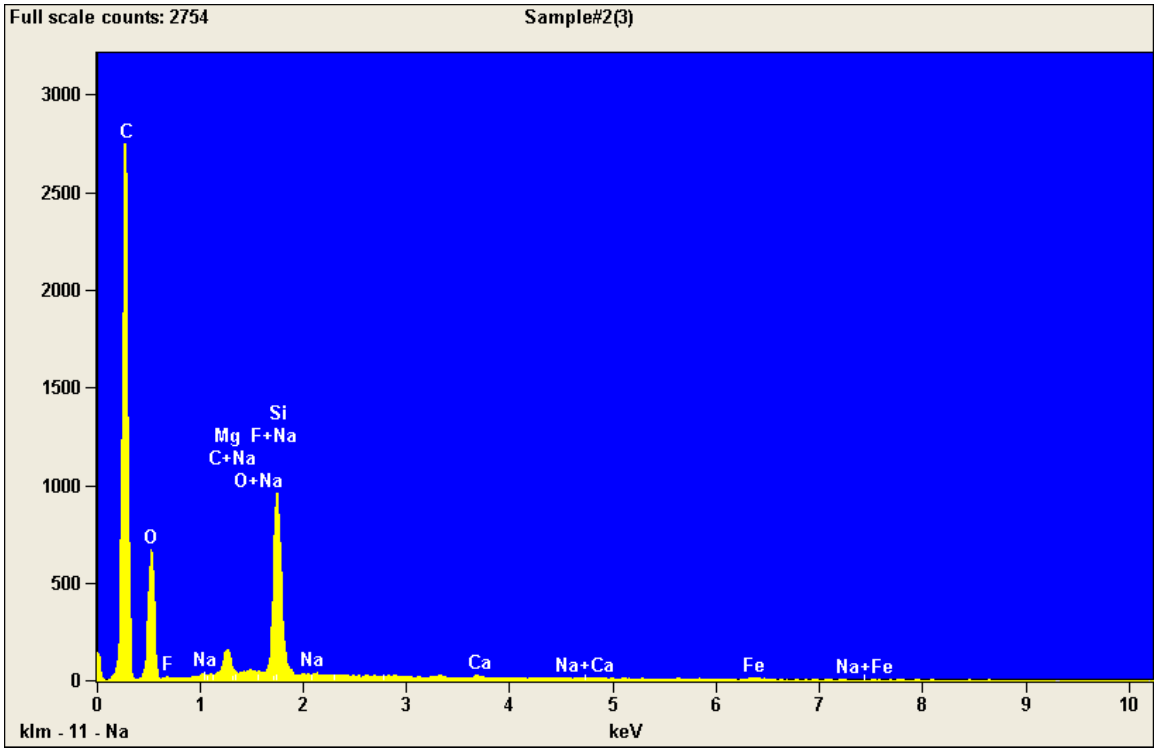
Element Line	***Net Counts***	***Net Counts Error***	***Weight %***	***Weight % Error***	***Atom %***	***Atom % Error***
O K	12005	+/- 288	42.00	+/- 0.50	55.82	+/- 1.34
Mg K	5369	+/- 266	4.54	+/- 0.11	3.97	+/- 0.20
Al K	27654	+/- 546	20.43	+/- 0.20	16.10	+/- 0.32
Si K	33821	+/- 554	30.24	+/- 0.25	22.90	+/- 0.38
K K	425	+/- 102	0.42	+/- 0.05	0.23	+/- 0.05
Ca K	502	+/- 104	0.52	+/- 0.05	0.27	+/- 0.06
Fe K	818	+/- 122	1.85	+/- 0.14	0.70	+/- 0.11
Total			100.00		100.00	



Live Time: 71.4 sec.

Quantitative Results for: Sample#2(2)

Element Line	*Net Counts*	*Net Counts Error*		*Weight %*	*Weight % Error*	*Atom %*	*Atom % Error*
O K	10071	+/-	258	52.30	+/- 0.67	65.71	+/- 1.68
F K	100	+/-	128	1.04	+/- 0.67	1.11	+/- 1.42
Na K	155	+/-	76	0.36	+/- 0.09	0.32	+/- 0.15
Mg K	4240	+/-	124	6.68	+/- 0.10	5.52	+/- 0.16
Al K	228	+/-	106	0.31	+/- 0.07	0.23	+/- 0.11
Si K	29387	+/-	404	35.92	+/- 0.25	25.71	+/- 0.35
K K	398	+/-	82	0.64	+/- 0.07	0.33	+/- 0.07
Ca K	392	+/-	86	0.66	+/- 0.07	0.33	+/- 0.07
Fe K	556	+/-	188	2.09	+/- 0.35	0.75	+/- 0.25
Total				100.00		100.00	



Live Time: 49.4 sec.

Quantitative Results for: Sample#2(3)

Element Line	*Net Counts*	*Net Counts Error*	*Weight %*	*Weight % Error*	*Atom %*	*Atom % Error*
O K	4183	+/- 172	58.03	+/- 1.19	70.53	+/- 2.90
F K	52	+/- 98	1.74	+/- 1.64	1.78	+/- 3.36
Na K	91	+/- 58	0.68	+/- 0.22	0.57	+/- 0.36
Mg K	1091	+/- 76	5.44	+/- 0.19	4.35	+/- 0.30
Si K	8461	+/- 222	31.30	+/- 0.41	21.67	+/- 0.57
Ca K	163	+/- 64	0.81	+/- 0.16	0.39	+/- 0.15
Fe K	178	+/- 74	2.00	+/- 0.42	0.70	+/- 0.29
Total			100.00		100.00	

Sample#2spot(1)

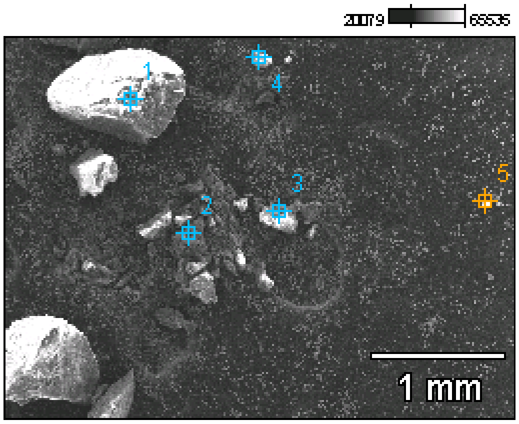
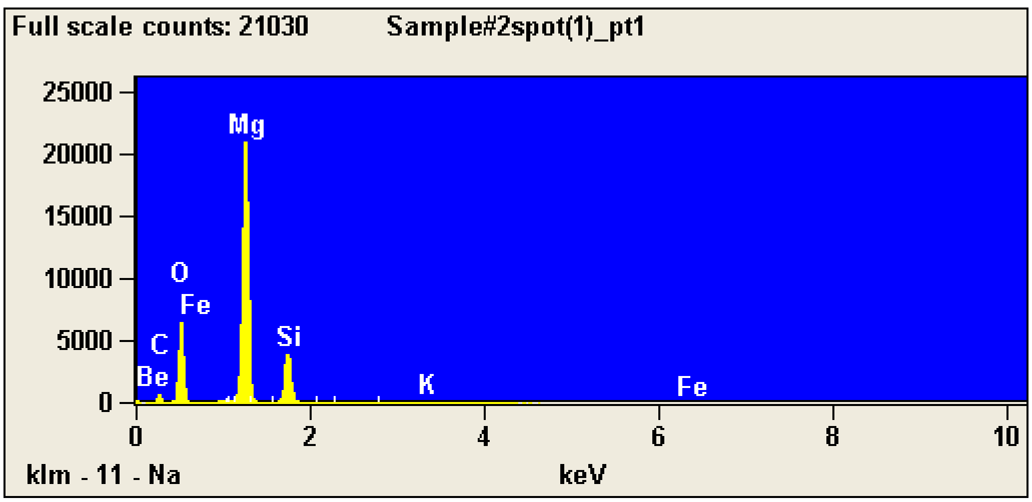
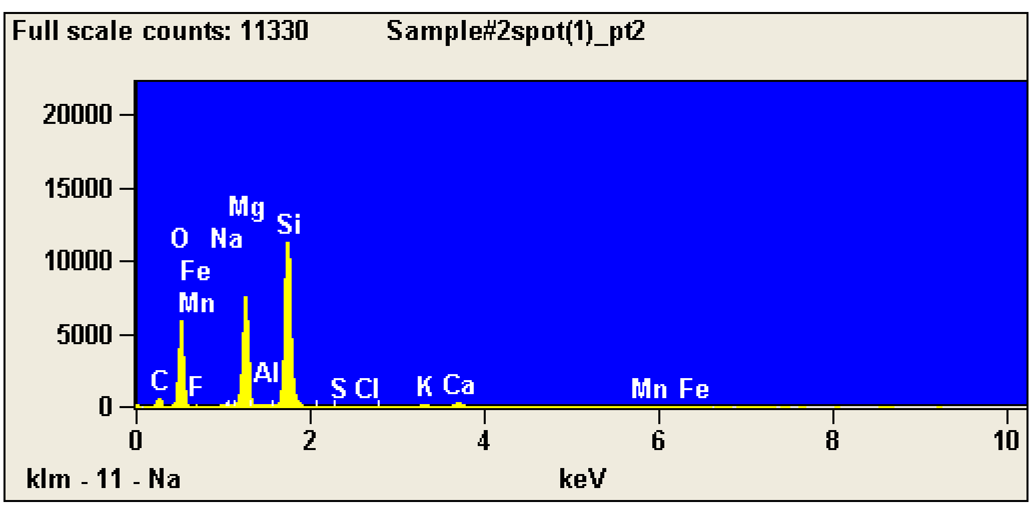


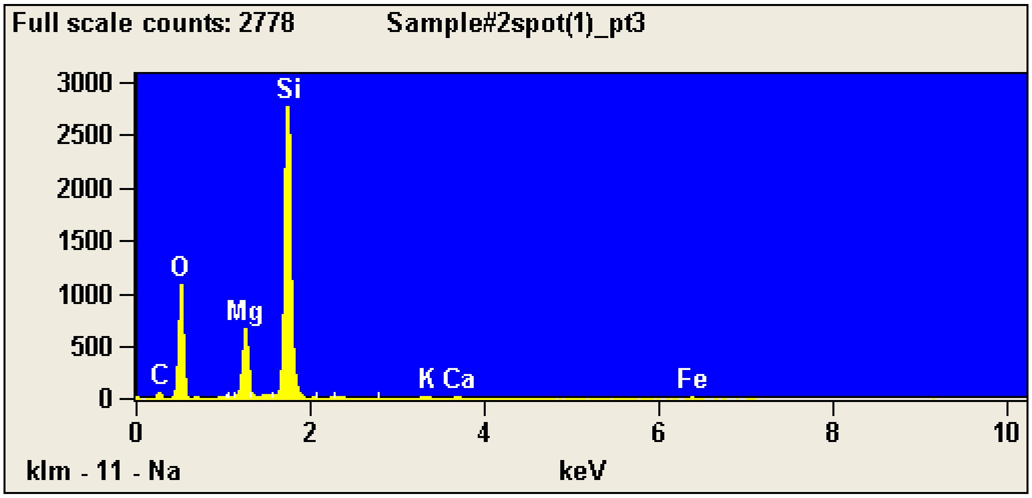
Image Name: Sample#2spot(1)

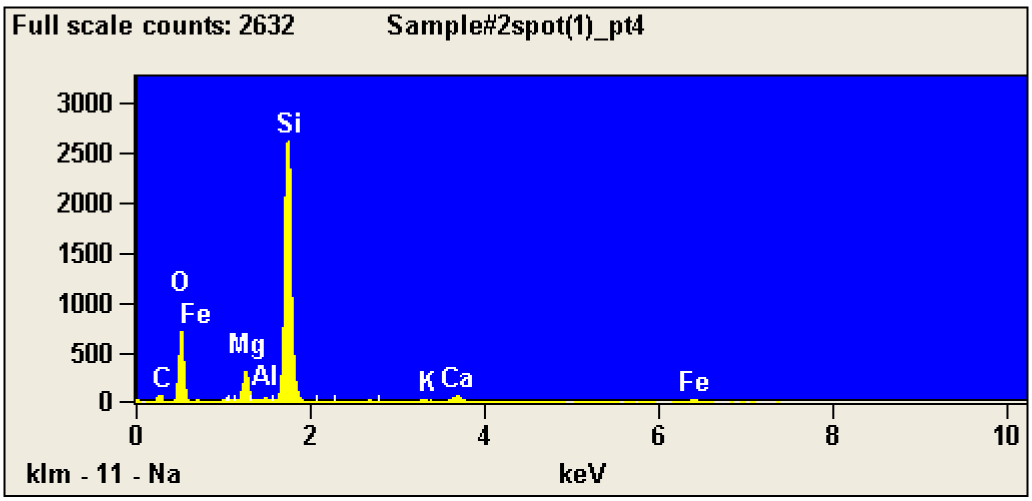
Accelerating Voltage: 20.0 kV

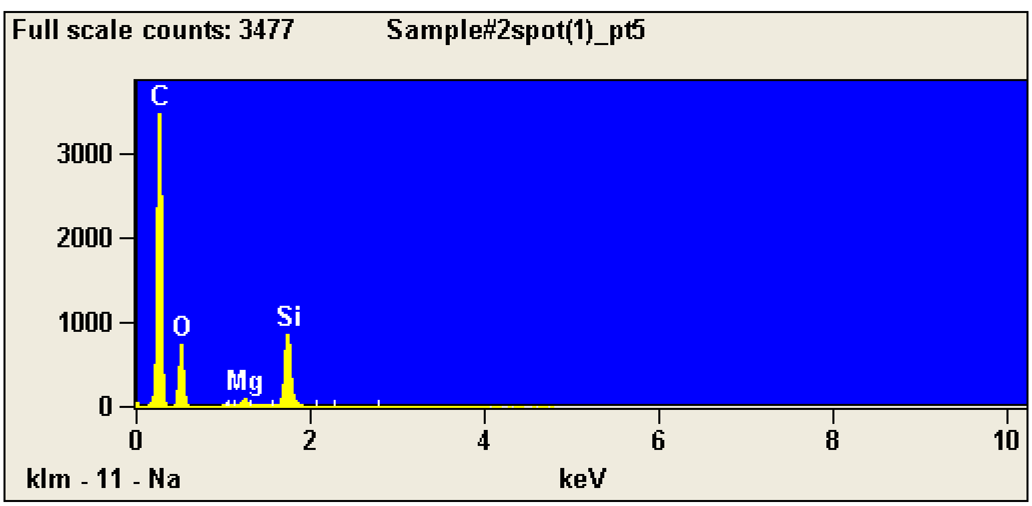
Magnification: 31

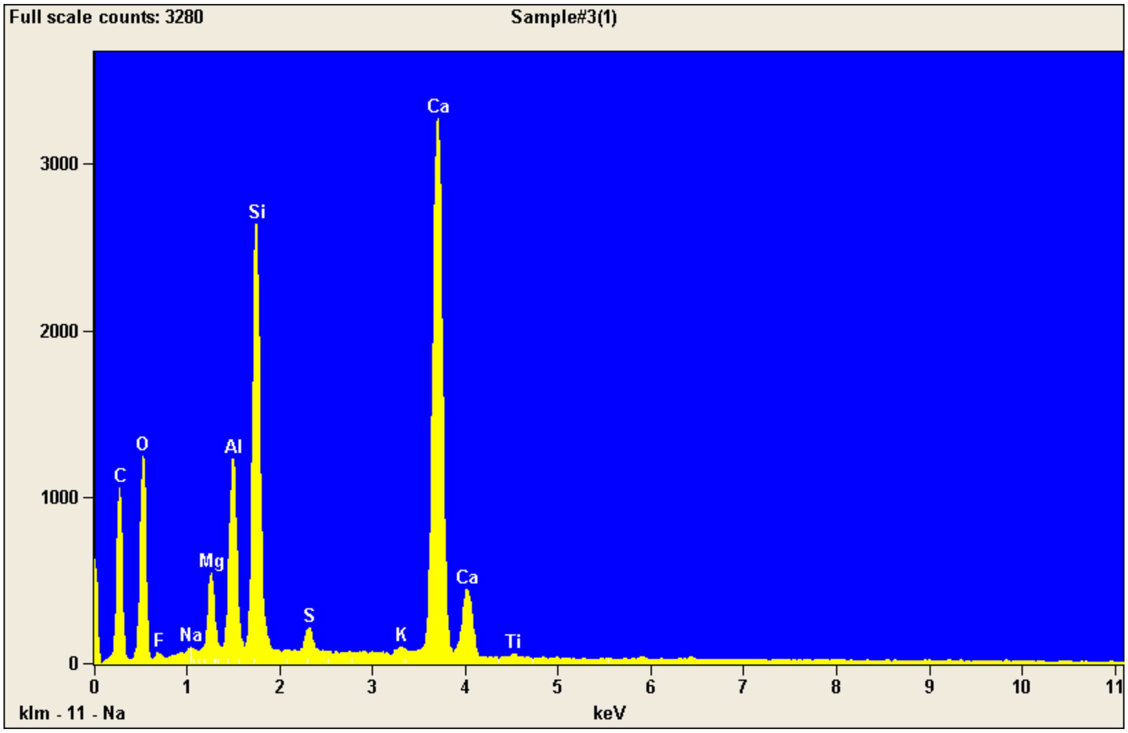





Full scale counts: 2778
Sample#2spot(1)_pt3
3000
2500
2000
1500
1000
500
0
Si
O
Mg
C
K Ca
Fe
0
2
4
6
8
10
klm - 11 - Na
keV


Full scale counts: 2632
Sample#2spot(1)_pt4
3000
2500
2000
1500
1000
500
0
Si
O
Fe
Mg
Al
C
K Ca
Fe
0
2
4
6
8
10
klm - 11 - Na
keV

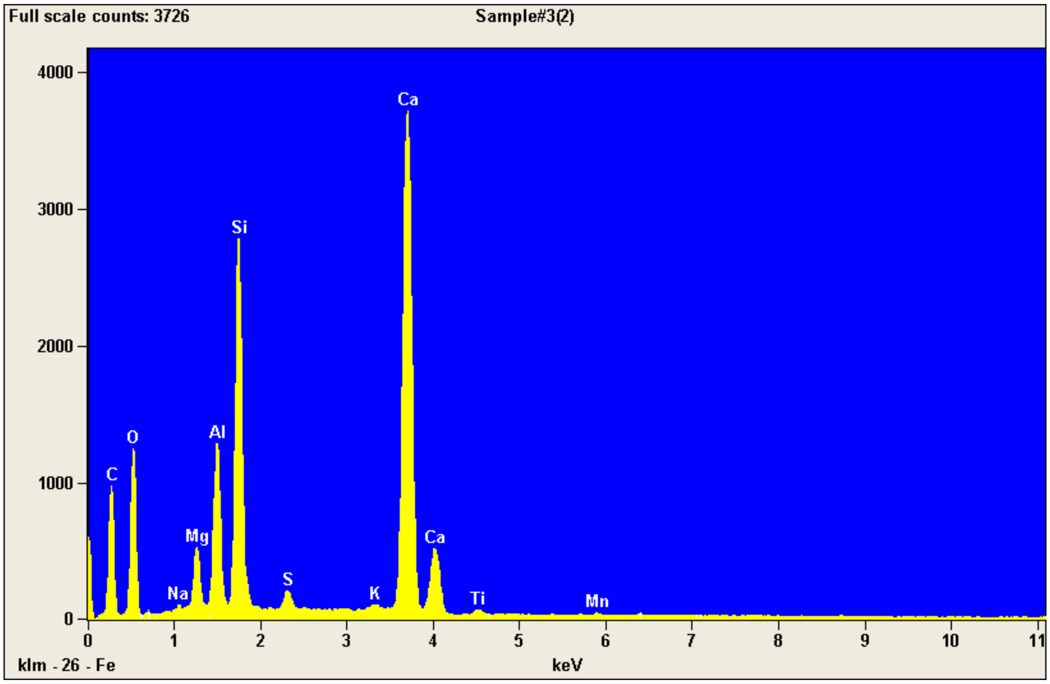

Full scale counts: 3477
Sample#2spot(1)_pt5
3000
2000
1000
0
C
O
Si
Mg
0
2
4
6
8
10
klm - 11 - Na
keV



Live Time: 100.0 sec.

Quantitative Results for: Sample#3(1)

Element Line	*Net Counts*	*Net Counts Error*	*Weight %*	*Weight % Error*	*Atom %*	*Atom % Error*
O K	7990	+/- 236	42.65	+/- 0.63	60.25	+/- 1.78
F K	264	+/- 108	1.51	+/- 0.31	1.80	+/- 0.74
Na K	149	+/- 96	0.18	+/- 0.06	0.18	+/- 0.12
Mg K	3466	+/- 228	2.79	+/- 0.09	2.59	+/- 0.17
Al K	9918	+/- 220	6.35	+/- 0.07	5.32	+/- 0.12
Si K	23880	+/- 444	14.61	+/- 0.14	11.76	+/- 0.22
S K	1729	+/- 136	0.98	+/- 0.04	0.69	+/- 0.05
K K	443	+/- 116	0.29	+/- 0.04	0.17	+/- 0.04
Ca K	40866	+/- 632	30.33	+/- 0.23	17.10	+/- 0.26
Ti K	265	+/- 98	0.30	+/- 0.06	0.14	+/- 0.05
Total			100.00		100.00	



Live Time: 100.0 sec.

Quantitative Results for: Sample#3(2)

Element Line	*Net Counts*	*Net Counts Error*	*Weight %*	*Weight % Error*	*Atom %*	*Atom % Error*
C K	6341	+/- 168	20.88	+/- 0.28	33.30	+/- 0.88
O K	7752	+/- 208	34.74	+/- 0.47	41.59	+/- 1.12
Na K	125	+/- 96	0.11	+/- 0.04	0.09	+/- 0.07
Mg K	3445	+/- 230	1.95	+/- 0.06	1.53	+/- 0.10
Al K	10486	+/- 226	4.71	+/- 0.05	3.34	+/- 0.07
Si K	24936	+/- 456	10.62	+/- 0.10	7.24	+/- 0.13
S K	1713	+/- 136	0.67	+/- 0.03	0.40	+/- 0.03
K K	420	+/- 120	0.20	+/- 0.03	0.10	+/- 0.03
Ca K	47204	+/- 684	25.33	+/- 0.18	12.10	+/- 0.18
Ti K	573	+/- 186	0.47	+/- 0.08	0.19	+/- 0.06
Mn K	265	+/- 122	0.33	+/- 0.08	0.11	+/- 0.05
Total			100.00		100.00	

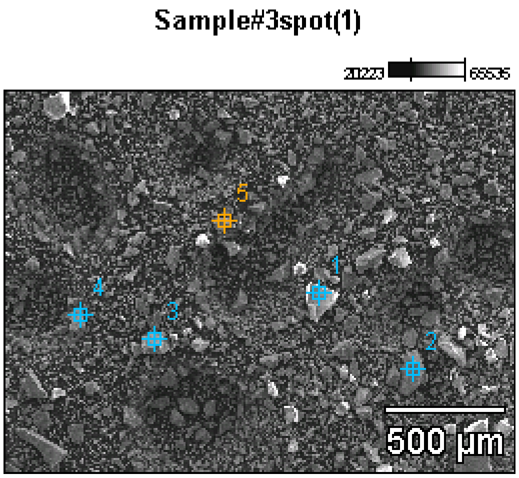
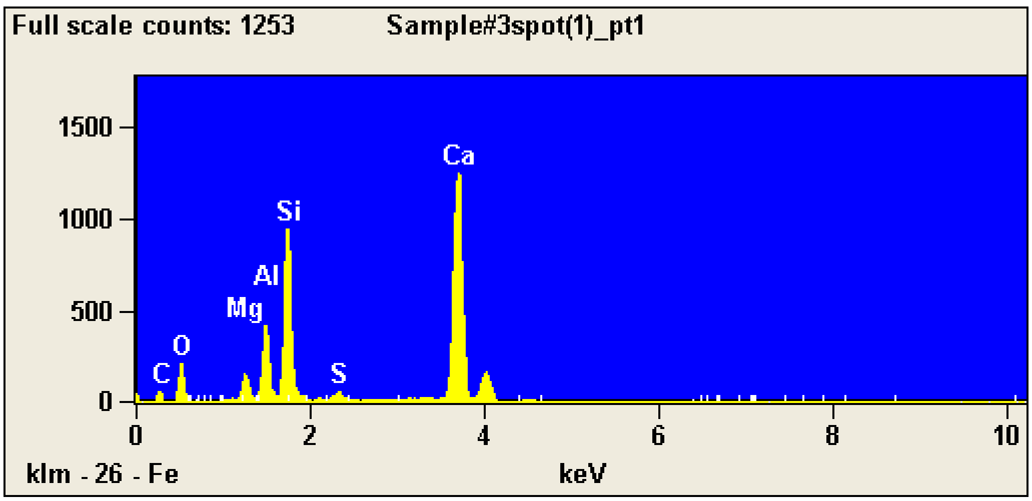
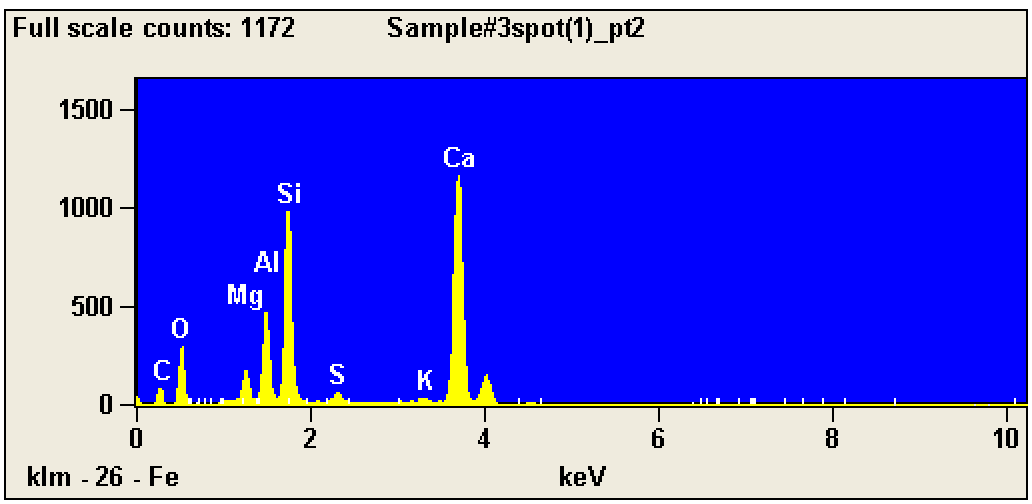


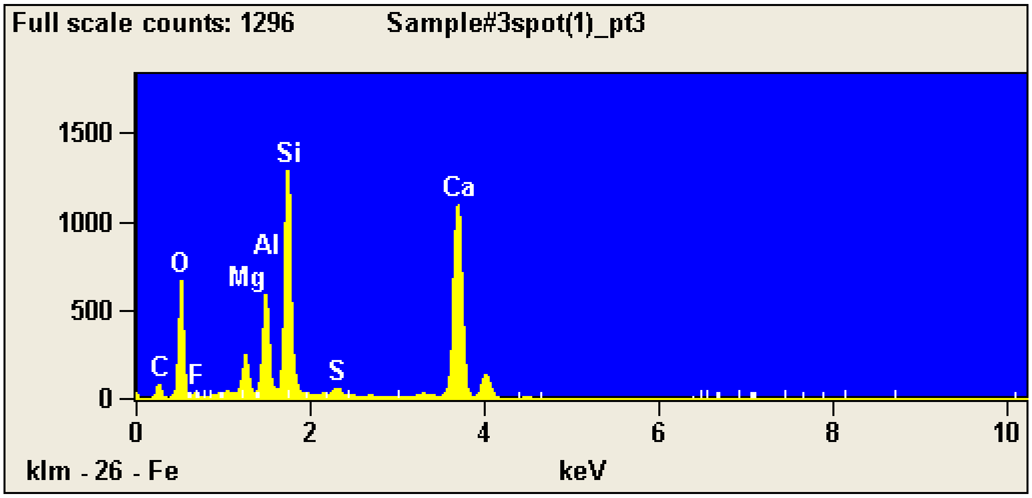
Image Name: Sample#3spot(1)

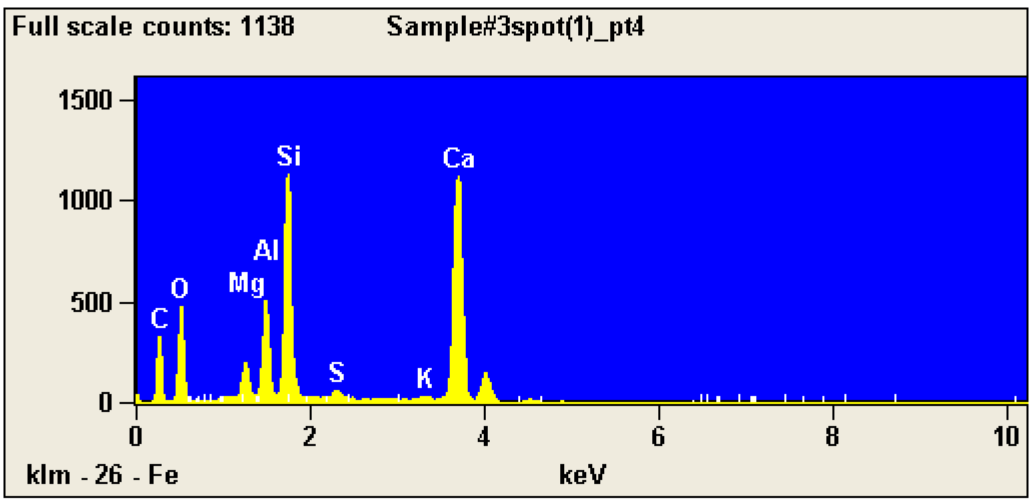
Accelerating Voltage: 20.0 kV

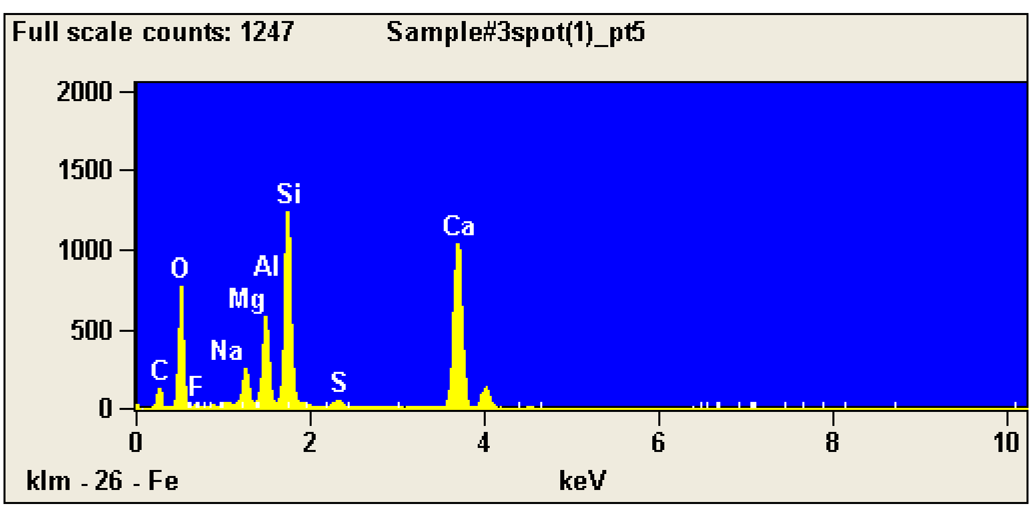
Magnification: 56

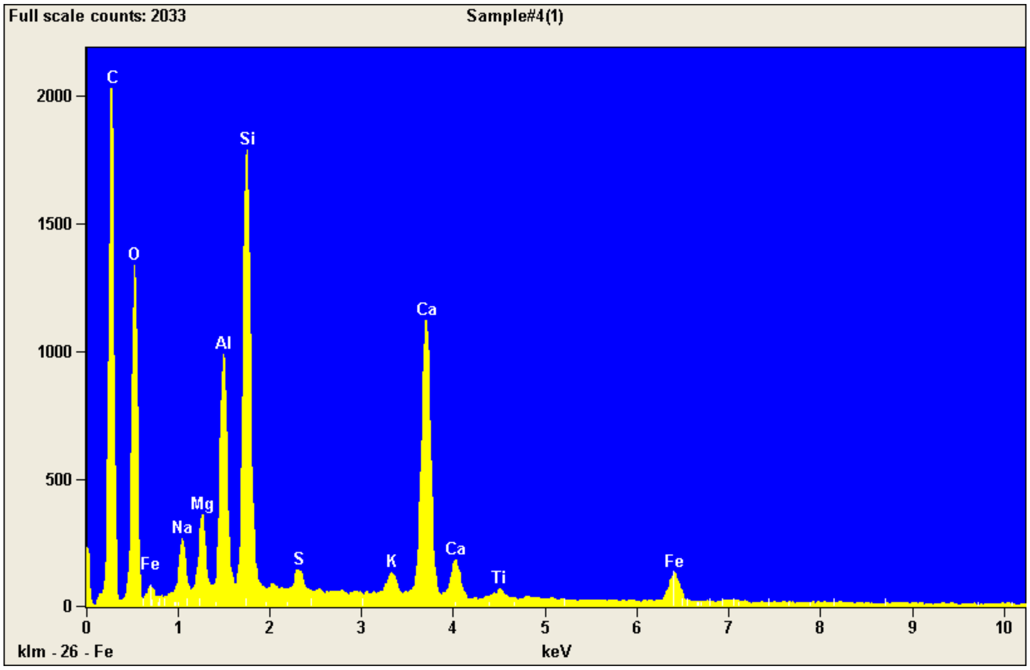





Full scale counts: 1296
Sample#3spot(1)_pt3
1500
1000
500
0
Si
Ca
Al
O
Mg
C
F
S
0
2
4
6
8
10
klm - 26 - Fe
keV


Full scale counts: 1138
Sample#3spot(1)_pt4
1500
1000
500
0
Si
Ca
Al
O
Mg
C
S
K
0
2
4
6
8
10
klm - 26 - Fe
keV

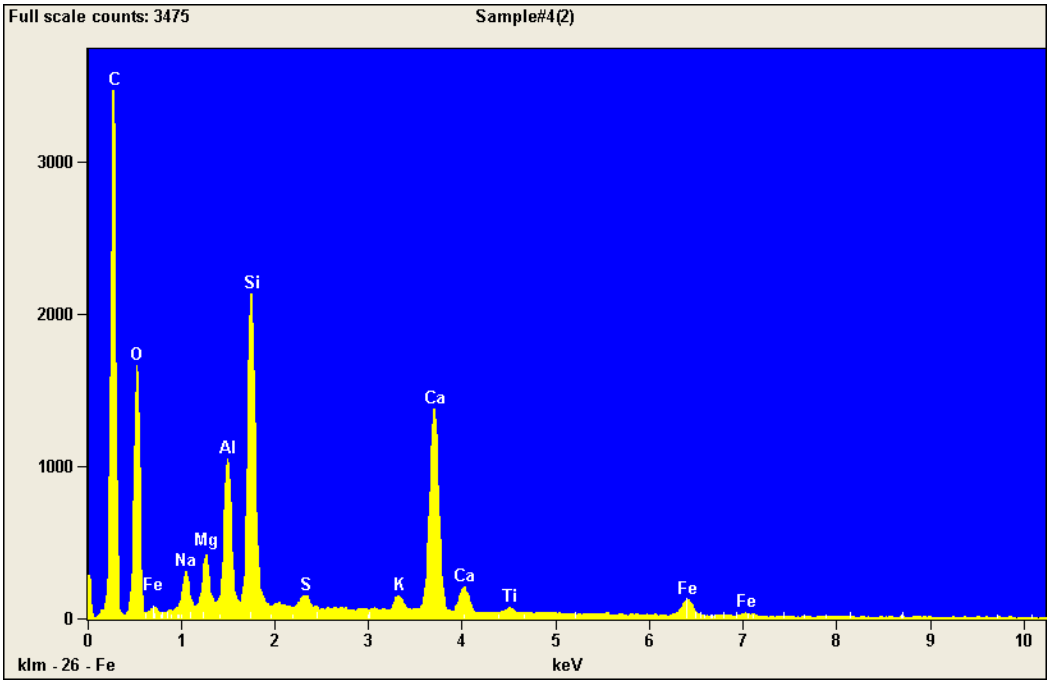

Full scale counts: 1247
Sample#3spot(1)_pt5
2000
1500
1000
500
0
Si
Ca
O
Al
Mg
Na
C
F
S
0
2
4
6
8
10
klm - 26 - Fe
keV



Live Time: 82.1 sec.

Quantitative Results for: Sample#4(1)

Element Line	Net Counts	Net Counts Error	Weight %	Weight % Error	Atom %	Atom % Error
C K	12590	+/- 294	39.11	+/- 0.46	52.23	+/- 1.22
O K	8226	+/- 258	34.57	+/- 0.54	34.66	+/- 1.09
Na K	1540	+/- 162	1.39	+/- 0.07	0.97	+/- 0.10
Mg K	2328	+/- 136	1.45	+/- 0.04	0.96	+/- 0.06
Al K	7876	+/- 188	3.88	+/- 0.05	2.31	+/- 0.06
Si K	16189	+/- 254	7.55	+/- 0.06	4.31	+/- 0.07
S K	1070	+/- 118	0.45	+/- 0.03	0.23	+/- 0.03
K K	1009	+/- 114	0.54	+/- 0.03	0.22	+/- 0.03
Ca K	13747	+/- 388	8.19	+/- 0.12	3.28	+/- 0.09
Ti K	495	+/- 176	0.43	+/- 0.08	0.14	+/- 0.05
Fe K	1697	+/- 250	2.42	+/- 0.18	0.70	+/- 0.10
Total			100.00		100.00	



Live Time: 100.0 sec.

Quantitative Results for: Sample#4(2)

Element Line	Net Counts	Net Counts Error	Weight %	Weight % Error	Atom %	Atom % Error
C K	20438	+/- 320	43.49	+/- 0.34	56.28	+/- 0.88
O K	10252	+/- 270	33.65	+/- 0.44	32.69	+/- 0.86
Na K	1835	+/- 116	1.24	+/- 0.04	0.84	+/- 0.05
Mg K	2596	+/- 140	1.21	+/- 0.03	0.77	+/- 0.04
Al K	8353	+/- 200	3.07	+/- 0.04	1.77	+/- 0.04
Si K	19417	+/- 284	6.70	+/- 0.05	3.71	+/- 0.05
S K	1203	+/- 224	0.38	+/- 0.04	0.18	+/- 0.03
K K	1096	+/- 122	0.45	+/- 0.02	0.18	+/- 0.02
Ca K	16776	+/- 432	7.53	+/- 0.10	2.92	+/- 0.08
Ti K	529	+/- 102	0.35	+/- 0.03	0.11	+/- 0.02
Fe K	1784	+/- 264	1.93	+/- 0.14	0.54	+/- 0.08
Total			100.00		100.00	

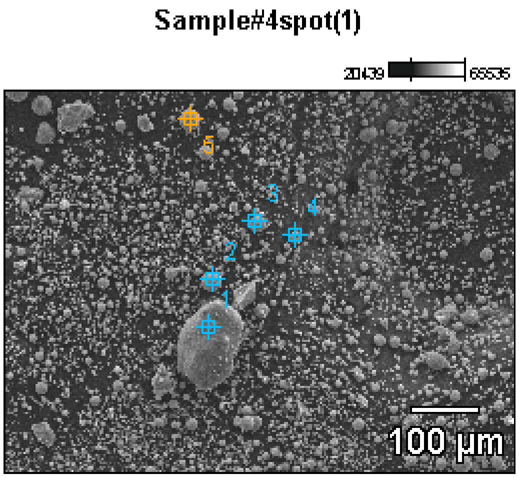
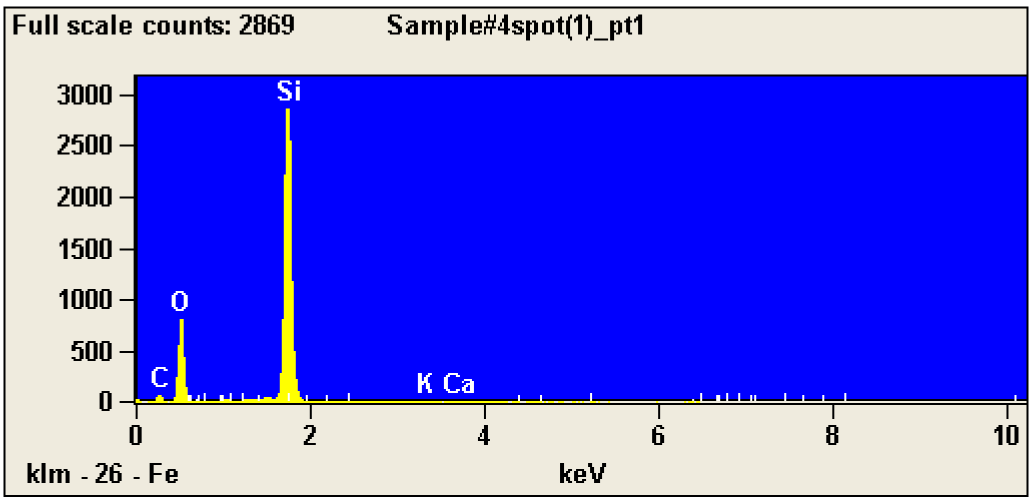
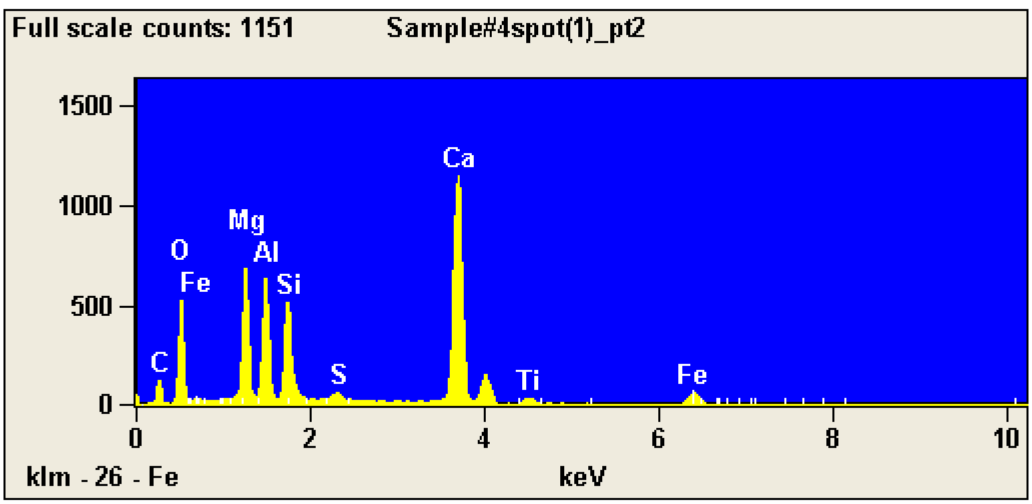


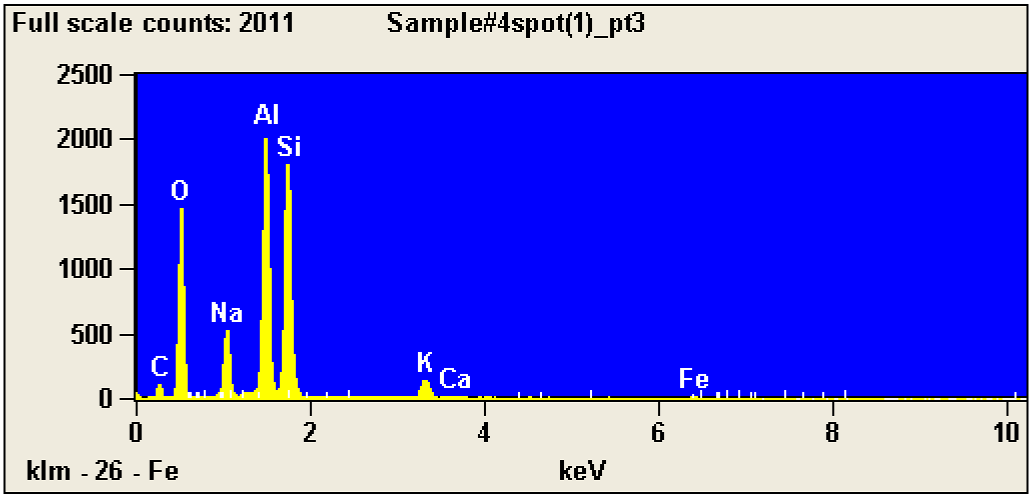
Image Name: Sample#4spot(1)

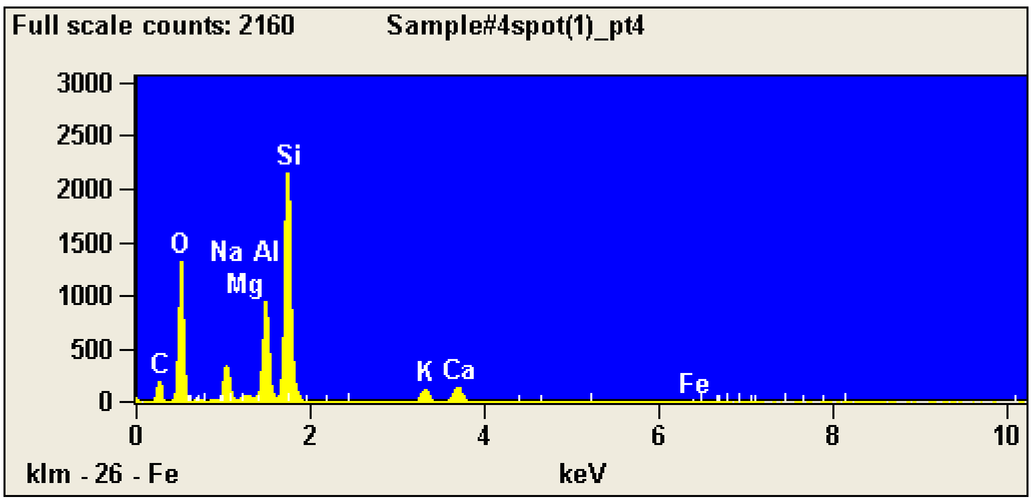
Accelerating Voltage: 20.0 kV

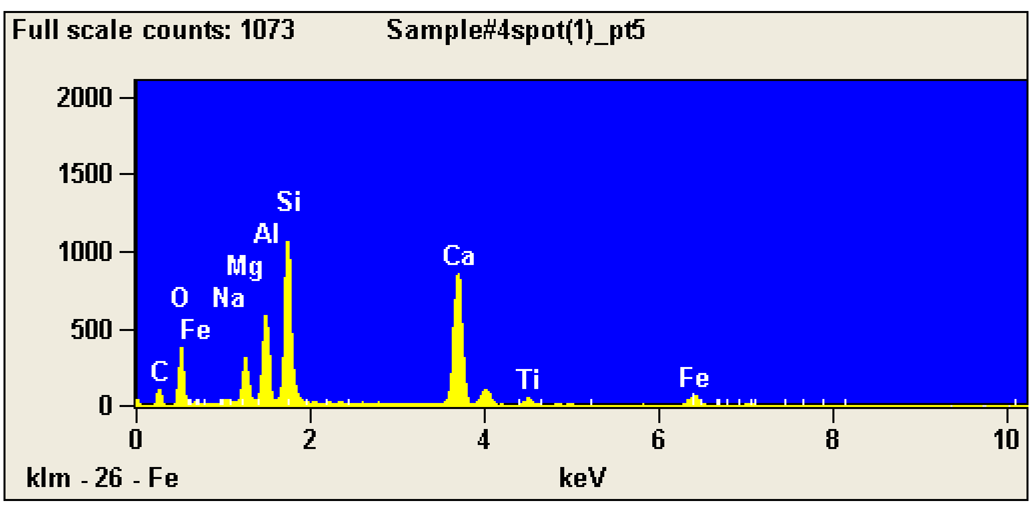
Magnification: 157






Full scale counts: 2011
Sample#4spot(1)_pt3
2500
2000
1500
1000
500
0
Al
Si
O
Na
C
K
Ca
Fe
0
2
4
6
8
10
klm - 26 - Fe
keV


Full scale counts: 2160
Sample#4spot(1)_pt4
3000
2500
2000
1500
1000
500
0
Si
O
Na
Al
Mg
C
K
Ca
Fe
0
2
4
6
8
10
klm - 26 - Fe
keV


Full scale counts: 1073
Sample#4spot(1)_pt5
2000
1500
1000
500
0
Si
Al
Mg
O
Na
Fe
C
Ca
Ti
Fe
0
2
4
6
8
10
klm - 26 - Fe
keV

APPENDIX-B: TECHNICAL SPECIFICATIONS OF SIKA VISCOCRETE-2100 (HRWRA)

Product Data Sheet
Edition 10.10.2014
Sika® ViscoCrete®-2100

Concrete

Sika® ViscoCrete®-2100
High Range Water Reducing Admixture

Description	Sika® ViscoCrete®-2100 is a high range water reducing and superplasticizing admixture utilizing Sika's 'ViscoCrete®' polycarboxylate polymer technology. Sika® ViscoCrete®-2100 meets the requirements for ASTM C-494 Types A and F.
Applications	Sika® ViscoCrete®-2100 may be used in both ready mix and precast applications, as a plant added high range water reducer to provide excellent plasticity while maintaining slump for up to 90 minutes. Controlled set times make Sika® ViscoCrete®-2100 ideal for horizontal and vertical applications, Sika® ViscoCrete®-2100 is ideal for production of Self Consolidating Concrete (SCC).
Benefits	**Water Reduction:** Sika® ViscoCrete®-2100 can be dosed in small amounts to obtain water reduction from 10-15%, and will achieve water reduction up to 45% at high dosage rates. Sika® ViscoCrete®-2100 is suitable for all levels of water reduction. **High Plasticity:** The superplasticizing action of Sika® ViscoCrete®-2100 provides high-slump, flowing concrete that maintains excellent workability and may be placed with minimal vibration even at very low water cement ratio's as low as 0.25. Sika® ViscoCrete®-2100 plasticized concrete is highly fluid while maintaining complete cohesion within the concrete matrix to eliminate excessive bleeding or segregation. **Extended Slump Life and Set Control:** Sika® ViscoCrete®-2100 has been formulated to provide controlled and predictable extended slump life for periods of 60 to 90 minutes with normal set times, The combined high range water reduction and superplasticizing action of Sika® ViscoCrete®-2100 provide the following benefits in hardened concrete: ■ Higher ultimate strengths allow for greater engineering design flexibility and structural economies. ■ Reduced water cement ratios produce more durable, dense concrete with reduced permeability. ■ Highly effective plasticizer reduces surface defects in concrete elements and improves aesthetic appearance. It has been formulated to provide maximum water reduction and extended slump retention at low dosages. Sika® ViscoCrete®-2100 is a non-chloride based admixture, it does not contain any intentionally added chlorides.
How to Use	
Dosage	Dosage rates will vary according to materials used, ambient conditions and the requirements of a specific project. Sika recommends dosage at 1-6 fl.oz. per 100 lbs. (65-390 ml/100 kg) of cementitious materials for conventional concrete applications. If high slump or Self Consolidating Concrete (SCC) is required, typically dosage from 5-12 fl.oz./100 lbs. (325-780 ml/100 kg) of cementitious materials may be used. Dosage rates outside the recommended range may be used where specialized materials such as microsilica are specified, extreme ambient conditions are encountered or unusual project conditions require special consideration. In this case, Please contact your local regional Sika representative or Sika Technical Service Department 1-800-933-7452 for more information and assistance.

Sika®

Mixing	For best superplasticizing results, add Sika® ViscoCrete®-2100 directly to freshly mixed concrete in the concrete mixer at the end of the batching cycle. Sika® ViscoCrete®-2100 may also be dispensed as an integral material during the regular admixture batching cycle or into freshly mixed concrete in a Ready-Mix truck at the concrete plant. To optimize the superplasticizing effect, after the addition Sika® ViscoCrete®-2100, Sika recommends that the combined materials be mixed for 80-100 revolutions, either in the concrete mixer or in the Ready-Mix truck. **Combination with Other Admixtures:** Sika® ViscoCrete®-2100 is highly effective as single admixture or in combination with other admixtures in the Sika System. If used in combination with certain Sikament® high range water reducers it may affect the plastic properties of fresh concrete. Please contact a Sika representative for further information. **Combination with Microsilica:** Sika® ViscoCrete®-2100 is particularly well suited for use with microsilica because of its water reduction capability and superior slump control.
Packaging	Sika® ViscoCrete®-2100 is available in 55 gallon drums (208 liters), 275 gallon totes (1040 liters) and bulk delivery.
Storage and Shelf Life	Sika® ViscoCrete®-2100 should be stored at above 40°F (5°C). If frozen, thaw and agitate thoroughly to return to normal state. Shelf life when stored in dry warehouse conditions between 50°F and 80°F (10°C - 27°C) is one year minimum.
Typical Data	
Appearance	Blue Liquid
Specific Gravity	Approx. 1.08

Concrete

KEEP CONTAINER TIGHTLY CLOSED • KEEP OUT OF REACH OF CHILDREN • NOT FOR INTERNAL CONSUMPTION • FOR INDUSTRIAL USE ONLY • FOR PROFESSIONAL USE ONLY

Sika Corporation
201 Polito Avenue
Lyndhurst, NJ 07071
Phone: (201) 933-8800
Fax: (201) 933-6225
usa.sika.com

Sika Canada Inc.
601, Delmar Avenue
Pointe-Claire, QC H9R 4A9
Phone: (514) 697-2610
Fax: (514) 697-3087
can.sika.com

Regional Information and Sales Centers. For the location of your nearest Sika representative, contact your regional center.

U.S. :	**Northeast:** Fairless Hills, PA, Phone: (215) 295-6600 **South East:** Conyers, GA, Phone: (770) 760-1300 **Western Region:** Santa Fe Springs, CA, Phone: (972) 289-6480	**North Central:** Ottawa, IL 61350, Phone: (815) 431-1080 **South Central:** Mesquite, TX, Phone: (972) 289-6480
Canada:	**Ontario:** Mississauga, ON, Phone: (905) 795-3177	**Alberta:** Edmonton, AB, Phone: (780) 486-6111

Quality Certification Numbers: Lyndhurst: FM 69711 (ISO 9000), FM 70421 (QS 9000), Marion: FM 69715, Kansas City: FM 69107, Santa Fe Springs: FM 69408

PRIOR TO EACH USE OF ANY SIKA PRODUCT, THE USER MUST ALWAYS READ AND FOLLOW THE WARNINGS AND INSTRUCTIONS ON THE PRODUCT'S MOST CURRENT PRODUCT DATA SHEET, PRODUCT LABEL AND SAFETY DATA SHEET WHICH ARE AVAILABLE ONLINE AT HTTP://USA.SIKA.COM/ OR BY CALLING SIKA'S TECHNICAL SERVICE DEPARTMENT AT 800-933-7452. NOTHING CONTAINED IN ANY SIKA MATERIALS RELIEVES THE USER OF THE OBLIGATION TO READ AND FOLLOW THE WARNINGS AND INSTRUCTION FOR EACH SIKA PRODUCT AS SET FORTH IN THE CURRENT PRODUCT DATA SHEET, PRODUCT LABEL AND SAFETY DATA SHEET PRIOR TO PRODUCT USE.

APPENDIX-C: MIXTURE DESIGNS FOR PCC MATERIAL CHARACTERIZATION FOR AASHTOWARE PAVEMENT ME DESIGN IMPLEMENTATION IN IDAHO

District 1

Centralia Mixture Design (paving concrete mixture design)

CONCRETE MIX CALCULATION

DATE: 24-Jul-15

FOR: ACME

PROJECT: i-90 Paving

MIX: Centralia Mix - Adj #1

W/C RATIO 0.38

WT.CU.FT. 144.55

	SSD WT.	VOLUME	BATCH WT.	Revised Mix for Moisture (CUBIC FEET 2.00)			MATERIAL SOURCE	S.S.D. SP.G
	-------	------	--------				------	----
Type I	550	2.80	550	40.74	pounds		Type I	3.15
Fly Ash	138	0.85	138	10.22		20%	Fly Ash	2.59
Silica Fume	0	0.00	0	0.00	pounds	0%	Silica Fume	2.20
Slag	0	0.00	0	0.00	pounds	0%	Slag	2.87
Coarse SAND	808	4.85	823	60.96	pounds	27%	C Sand	2.67
1 1/2	541	3.28	539	39.91	pounds	18%	1 1/2	2.64
3/4	1262	7.66	1250	92.57		43%	3/4	2.64
Fine Sand	346	2.06	345	25.54	pounds	12%	3/8	2.69
WATER	31.0	4.14	31.1	19.21	pounds		WATER	1.00
AIR%	5.0%	1.35	5.0%				AIR ENTRAINED	
AIROZ/100	1.00		6.9	15.02	mL			AE-90
WROZ/100	5.00	---	34	75.08	mL		WATER REDUCER	POZZ 80
SWR/100	0.00	---	0	0.00	mL		SUPER PLASTICIZER	
	----	VOLUME						
TOTAL WT	3903	27.00						

c/a ratio	60.98%		
% MORTAR	50%	PASS #8	90.0%

TARGET VOLUME	27.00
Total Moisture - Sand	5.25%
Total Moisture - 1 3/8"	1.00%
Total Moisture - 3/4"	0.50%
	0.50%

Interstate Class 40A (structural concrete mixture design)

INTERSTATE
CONCRETE & ASPHALT

CONCRETE MIX DESIGN

PROJECT:	SH-5 RAILROAD BR, PLUMMER	DATE:	03/24/15
CONTRACTOR:	RALPH L. WADSWORTH CONSTRUCTION	SLUMP:	3.5"
MIX DESIGN:	320006 ITD CLASS 40 A	w/ Super P:	8.5" MAX
PLANT LOCATION:	INTERSTATE	W/C:	.44 MAX
CEMENT TYPE:	LAFARGE I-II	AIR:	5.0%-8.0%
PRODUCT USE:	CLASS 40 A		

DISPATCH:
208-712-2030

AGGREGATE	SPECIFIC GRAVITY
3/4" ROCK	2.62
ITD FINE AGG	2.59

DESCRIPTION	VOLUME	WEIGHTS
CEMENT	3.11	611
FLYASH	0.00	0
OTHER	0.00	0
WATER	4.13	258
3/4" ROCK	11.32	1850
ITD FINE AGGREGATE	6.69	1081
AIR PERCENT	1.76	6.5%
TOTAL	27.00	3800

ADMIXTURES: AIR ENTRAINMENT ADMIXTURE, WATER REDUCING ADMIXTURE.

REMARKS: MAY BE PLACED BY CHUTE OR PUMP.

Edward Benson
QUALITY CONTROL

District 2

Atlas

Atlas Concrete
4341 Snake River Ave.
Lewiston , Idaho , 83501
208-746-9985

Concrete Mix Design
Mix 8
Strength Compressive: 4,000 psi

Contractor : Stillwater Electric
Project : Thain And Grelle Intersection
Source of Concrete : Atlas Concrete
Construction Type : Class 40
Placement : Tailgate/Pump

Weights per Cubic Yard (Saturated, Surface-Dry)	Quantity	Density	Yield, ft³
ASTM C-150 Type I/II Cement, lb	489	3.150	2.49
ASTM C-618 Class F Fly Ash, lb	122	2.600	0.75
Well Water , lb	265	1.000	4.25
ASTM C-33 Coarse Aggregate , lb	1,721	2.720	10.14
ASTM C-33 Fine Aggregate , lb	1,246	2.640	7.57
ASTM C-494 Type A Water Reducer , oz (US)	45.0	1.000	0.05
ASTM C-260 Air Entrainment , oz (US)	5.0	1.000	0.01
Total Air, %	6.5 ± 1.5		1.76
		TOTAL	27.00

Water/Cement Ratio, lbs/lb	0.43
Slump, High, in	5.00
Low, in	3.00
Super Plasticizer High, in	8.00
Super Plasticizer Low, in	5.00
Concrete Unit Weight, pcf	142.47
Yield, %	100.0

Exposure Condition : Moderate exposure

ACTUAL BATCH WEIGHTS WILL VARY DEPENDING ON THE MOISTURE CONTENT OF THE CONCRETE AGGREGATES. ACCEPTANCE OF THIS MIX CARRIES WITH IT THE INCLUSION OF ATLAS CONCRETE ON THE DISTRIBUTION LIST OF ALL TEST REPORTS PLASTISIZER, STABILIZER ON REQUEST

Prepared by :

Dennis Anderson

Accumix

Accumix

CONCRETE MIX DESIGN

Mix ID Number:	40 Class A	Date:	26-Aug-15
Design Strength:	4000 psi	Plant:	Grangeville
	28 MPa	Designed By:	Accumix

MIX DESIGN QUANTITIES:

			English Units		Metric Units	
Material	Product/Source	Spec Grav	Weight	Volume (ft3)	Mass	Volume (m3)
Cement	Ash Grove Durkee, Type I-II	3.15	500 lb	2.54	297 kg	0.094
Fly Ash	ENX Genesee Class F	2.03	125 lb	0.99	74 kg	0.036
Silica Fume	Basf	2.20	0 lb	0.00	0 kg	0.000
Water (Total)	City Source	1.00	250 lb	4.01	148 kg	0.148
3/4-#4	Salmon River Pit	2.76 *	1660 lb*	9.64	985 kg*	0.357
Ground Limestone	John Day Cr. Pit	2.68 *	0 lb*	0.00	0 kg*	0.000
		2.60 *	0 lb*	0.00	0 kg*	0.000
Fine Aggregate	Salmon River Pit	2.68 *	1350 lb*	8.07	804 kg*	0.300
			lb			
	Total Mix Weight:		3885 lb		2308 kg	
	Air (Entrap/Entrain)	6.5 %		1.76		0.065
	Total Mix Volume:			27.01		1.000

ADMIXTURES:

Product	Product Name/Type	Dosage Rate	Dosage (English)	Dosage (Metric)
Air Entrainment	Basf AE-90	0.28 oz/cwt**	1.8 oz/cy**	70 mL/m3**
Water Reducer	322N	4.0 oz/cwt**	25.0 oz/cy**	968 mL/m3**
Superplasticizer	Basf Z60	4.0 oz/cwt**	25.0 oz/cy**	968 mL/m3**
Superplasticizer	Basf Glenium 3030	2.0 oz/cwt**	13.0 oz/cy**	503 mL/m3**
Hydration Stabilizer	Basf Delvo	0.0 oz/cwt**	0.0 oz/cy**	0 mL/m3**
Accelerator	Basf NC534	0.0 oz/cwt**	0.0 oz/cy**	0 mL/m3**
Fibers		0.0 lb/cy**	0.0 lb/cy**	0.0 kg/m3**

MIX DESIGN PROPERTIES:

Aggregate Properties:	SG	Abs	FM	Dry Rodded Unit Wt	
3/4-#4	2.76	1.3%	n/a	101.0 pcf	1618 kg/m3
Ground Limestone	2.68	0.2%	n/a	pcf	kg/m3
	2.60	3.1%	n/a	pcf	kg/m3
Fine Aggregate	2.68	1.6%	2.90	n/a	n/a

Plastic Properties:	Slump:	6.0 ± 2.0 inch		150 ± 50 mm
	Air Content:	6.5 ± 1.5 %		
	Unit Weight:	143.8 pcf		2308 kg/m3
Design Properties:	Total Cementitious:	625 lb		371 kg
	Fly Ash Replacement:	20.0 %	W/C Ratio:	0.40 (incl Admix)

Project:

Contractor:

Comments: W/C ratio can be increased to but not exceed .42

Usage:

Footnotes: * SSD Weights and Spec Gravities. **Admixture dosage rates will be adjusted according to manufacturer's recommendations to accommodate varying field conditions.

This mix design is predicated on the specific information and/or materials provided by the customer and therefore. Change in design components or proportions, materials gradations and/or field placement and curing practices will all strongly affect the ultimate quality of concrete. User should confirm each laboratory design with concrete batched on site and then routinely run quality control checks to verify yield, air content and compressive strength because the physical and chemical characteristics of materials may vary.

District 3

Concrete Placing Company
6451 West Gowen Road
Boise, Idaho 83709
Phone: 208.362.2100 Fax: 208.362.2220

CONCRETE MIX DESIGN REPORT BIC/MIC_500_125 Mix#2014_001
Compressive Strength: 5600

Contractor:	Concrete Placing Company
Project:	Broadway IC A009(081), A012(029) & A012(379)
Source of Concrete:	Portable Wet Batch
Project Type:	4500 PSI Paving
Placement Type:	Slipform

Material / Source or Designation / Blend[1]	Quantity (SSD)	S.G.	Yield, ft^3
Type I/II Cement / Ash Grove Cement / 80%	500 lb	3.15	2.54
Type F Ash (Bridger) / Head Waters / 20%	125 lb	2.36	0.85
Water / Boise City Water	248 lb	1.00	3.97
1 1/2" / 1.5" / 17.96%	524 lb	2.61	3.22
3/4" / .75" / 42.05%	1227 lb	2.61	7.54
Sand / Sand / 39.99%	1167 lb	2.59	7.23
Total Air, percent	6%		1.62
AE 90 / BASF	5 fl oz,(US)	1.01	0.00
Pozz 80 / BASF	30 fl oz (US)	1.20	0.03
			27.00

[1] The blend percentage indicated (by weight) is listed separately for cementitious materials and aggregates.

Total Water Content (including water in admixtures), lb		250		
Water / Cementitious Material Ratio:		0.4		
Concrete Unit Weight, pcf		140.5		
Target Slump, in.		1.5 ± 0.5		
Paste Content, percent		27.39%		
Workability Factor (WF)	Target:	35.0	Actual:	36.8
Coarseness Factor (CF)	Target:	60.2	Actual:	58.5
Prepared On:		7/10/14 3:17 PM		

Prepared By:

District 4

Class 40A (paving concrete mixture design)

"When Performance Counts"
KLOEPFER INC
READY MIX CONCRETE & ASPHALT PAVING COMPANY

Paul
Voice: (208) 438-4525
Fax: (208) 438-5030
505 E. Ellis
P.O. Box 840
Paul, ID 83347

Burley
Voice: (208) 678-9293
Over 50 Years
Of Service to the Entire Magic Valley
"an Equal Opportunity Employer"

Twin Falls
Voice: (208) 734-3924
Fax: (208) 734-3928
751 Madrona St. S.
Twin Falls, ID 83301

"Quality Control Department"

Concrete Mix Design "Absolute Volume Method"
DECLO TO SALT LAKE INTERCHANGE
MIX DESIGN # CLASS 40A
6.5 SACK 0% FLY ASH WITH LITHIUM 4000 P.S.I. (28 DAY LAB CURE)

Report To:	DOUG CLEMENTS	*Cement Brand:*	A.G.
Contractor:	RALPH WADSWORTH CONST.	*Cement Type:*	1&2
Project:	DECLO TO S.L. INTERCHANGE	*Sack Mix:*	6.5
Structure:	4000 P.S.I.	*Specified P.S.I. :*	4000
Design Date:	2/16/10	*Basic Mix Strength P.S.I.:*	4485

Design CF/CY:	27	*Water Lbs./Gal.:*	8.34	*Water Lbs./CF:*	62.4
Water Gal/CY:	32.0	*Water Lbs./CY:*	266.88	*Water CF/CY:*	4.28
% of Air:	0.065	*% of Cement:*	1.00	*Air - CF/CY:*	1.76
% of Fly-Ash:		*Cement Sacks/CY:*	6.50	*% of Cement & Fly-Ash:*	1.00
Fly-Ash Sks/CY:		*Cement Lbs/CY:*	611	*Cement/Fly-Ash Lbs/Sk:*	94.0
Fly-Ash Lbs/CY:				*Cement/Fly-Ash Lbs/CY:*	611
Fly-Ash Sp.Gr.:	2.25			*Fly-Ash CF/CY:*	
Cement Sp.Gr.:	3.15			*Cement CF/CY:*	3.11
Agg. CF/CY:	17.85			*Total Paste CF/CY:*	9.15

MIX COMPONENT		STATE SOURCE NUMBER	QUANTITY	SP.GR.	A.R.		[1] 1 YD. WEIGHT S.S.D.
Acequia Coarse Agg. Size 2B		MD45	58.0%	2.596	1.60%		1677
Coarse Sand (Fine Agg.)		MD45	30.0%	2.511	2.80%		840
Blend Sand (Fine Agg.)		MD36c	12.0%	2.595	1.50%		347
Cement	A.G. Type 1&2		100.0%	3.15			611
Fly-Ash	Type F			2.25			
Water						Lbs./Yd.	267
						Gal./Yd.	32
						TOTAL BATCH WEIGHT	3741

AIR ENTRAINMENT	MASTER BUILDERS (MBAE90)	[2] 8	OZ./YD.
LITHIUM	MASTER BUILDERS (ASRx)	2	GAL./YD.
CONCRETE STABILIZER	MASTER BUILDERS (DELVO)	31	OZ./YD.

[1] WEIGHTS MUST BE ADJUSTED FOR CURRENT MOISTURE IN EACH AGGREGATE
[2] DOSAGE MUST BE ADJUSTED FOR DESIRED AIR CONTENT IN THE FIELD

DESIGN PROPERTIES

Max. Slump ("):	3.50
% of Air (Entrained):	6.50%
Fresh Unit Weight (lb. / yd.^{3}):	3741
Fresh Unit Weight (lb. / ft.^{3}):	138.55
Yield (ft.^{3} / yd.^{3}):	27.0
W/C+cm Ratio:	0.44

The specified strength for this design as delivered is 4000 psi lab cure in 28 days. The required avg. or designed strength of the mix is 4485 psi lab cure in 28 days as delivered, according to provisions set forth in *ITD* Specifications. It is designed for the allowances as outlined, and is not to be confused with the specified strength. The specified strength will be met provided all *AASHTO* Methods and Standards for field testing of the concrete as delivered are met precisely. AASHTO Standards for Field Technician, Curing, Labs, and Lab Technician must also be met precisely, and all criteria of this mix design must be followed. Reporting, and Evaluating the acceptance of the concrete as delivered, must be in compliance to AASHTO Methods. Acceptance of this mix design acknowledges acceptance of the preceding standards.

DESIGNED BY Steven L. Straubhaar

Steven L. Straubhaar
V.P.

Class 40B (paving concrete mixture design)

"When Performance Counts"

KLOEPFER INC
READY MIX CONCRETE
& ASPHALT PAVING COMPANY

Paul
Voice: (208) 438-4525
Fax: (208) 438-5030

505 E. Ellis
P.O. Box 840
Paul, ID 83347

Burley
Voice: (208) 678-8293

Over 50 Of Service to the Entire Magic Valley

"an Equal Opportunity Employer"

Twin Falls
Voice: (208) 734-3924
Fax: (208) 734-3928

751 Madrona St. S.
Twin Falls, ID 83301

"Quality Control Department"

Concrete Mix Design "Absolute Volume Method"
DECLO TO SALT LAKE INTERCHANGE
MIX DESIGN # CLASS 40B

6.5 SACK 0% FLY ASH WITH LITHIUM 4000 P.S.I. (28 DAY LAB CURE)

Report To: DOUG CLEMENTS	*Cement Brand:* A.G.
Contractor: RALPH WADSWORTH CONST.	*Cement Type:* 1&2
Project: DECLO TO S.L. INTERCHANGE	*Sack Mix:* 6.5
Structure: 4000 P.S.I.	*Specified P.S.I. :* 4000
Design Date: 2/16/10	*Basic Mix Strength P.S.I.:* 4485

Design CF/CY: 27	*Water Lbs./Gal.:* 8.34	*Water Lbs./CF:* 62.4
Water Gal/CY: 32.0	*Water Lbs./CY:* 266.88	*Water CF/CY:* 4.28
% of Air: 0.065	*% of Cement:* 1.00	*Air - CF/CY:* 1.76
% of Fly-Ash:	*Cement Sacks/CY:* 6.50	*% of Cement & Fly-Ash:* 1.00
Fly-Ash Sks/CY:	*Cement Lbs/CY:* 611	*Cement/Fly-Ash Lbs/Sk:* 94.0
Fly-Ash Lbs/CY:		*Cement/Fly-Ash Lbs/CY:* 611
Fly-Ash Sp.Gr.: 2.25		*Fly-Ash CF/CY:*
Cement Sp.Gr.: 3.15		*Cement CF/CY:* 3.11
Agg. CF/CY: 17.85		*Total Paste CF/CY:* 9.15

MIX COMPONENT		STATE SOURCE NUMBER	QUANTITY	SP.GR.	A.R.		[1] ***1 YD. WEIGHT S.S.D.***
Acequia Coarse Agg. Size 2B		MD45	58.0%	2.596	1.60%		***1677***
Coarse Sand (Fine Agg.)		MD45	30.0%	2.511	2.80%		***840***
Blend Sand (Fine Agg.)		MD36c	12.0%	2.595	1.50%		***347***
Cement	A.G. Type 1&2		100.0%	3.15			***611***
Fly-Ash	Type F			2.25			
Water						Lbs./Yd.	***267***
						Gal./Yd.	***32***
						TOTAL BATCH WEIGHT	***3741***

AIR ENTRAINMENT	MASTER BUILDERS (MBAE90)	[2] 8	OZ./YD.
LITHIUM	MASTER BUILDERS (ASRx)	2	GAL./YD.
CONCRETE STABILIZER	MASTER BUILDERS (DELVO)	[3] 31	OZ./YD.
WATER REDUCER	MASTER BUILDERS POLYHEED 1020	24	OZ./YD.

[1] WEIGHTS MUST BE ADJUSTED FOR CURRENT MOISTURE IN EACH AGGREGATE
[2] DOSAGE MUST BE ADJUSTED FOR DESIRED AIR CONTENT IN THE FIELD
[3] FOR COUNTERACTING THE LITHIUM ONLY - MAY NEED TO BE OMITTED IN COLD WEATHER

DESIGN PROPERTIES

Max. Slump ("):	5.00
% of Air (Entrained):	6.50%
Fresh Unit Weight (lb. / yd.³):	3741
Fresh Unit Weight (lb. / ft.³):	138.55
Yield (ft.³ / yd.³):	27.0
W/C+cm Ratio:	0.44

The specified strength for this design as delivered is 4000 psi lab cure in 28 days.
The required avg. or designed strength of the mix is 4485 psi lab cure in 28 days
as delivered, according to provisions set forth in *ITD* Specifications. It is designed for the allowances as outlined, and is not to be confused with the specified strength. The specified strength will be met provided all *AASHTO* Methods and Standards for field testing of the concrete as delivered are met precisely. AASHTO Standards for Field Technician, Curing, Labs, and Lab Technician must also be met precisely, and all criteria of this mix design must be followed. Reporting, and Evaluating the acceptance of the concrete as delivered, must be in compliance to AASHTO Methods. Acceptance of this mix design acknowledges acceptance of the preceding standards.

DESIGNED BY

Steven L. Straubhaar
V.P.

Interstate Class 40A (structural concrete mixture design)

AUG-22-2006 11:14 STRATA INC 2083768201 P.01/01

STRATA

Integrity from the Ground Up

CONCRETE MIX DESIGN

Client:	Kloepfer Concrete	Date:	8/18/2006
		Client No.:	KLOEPE
Project:		Project No.:	BM06011

Mix Identification:

Mix Date:	8/1/2006
Mix ID:	Silica Fume
Minimum Design Strength, psi:	8,200

Mix Components:

Cement:	Ash Grove Inkom	660	lbs	7.02	Sacks
Silica:	MB - Micro Silica	50	lbs		
Water:	Well	260	lbs	31.2	Gallons

Aggregate: Batch Weight at Saturated Surface Dried Condition (SSD)

Coarse:	1/2" Conc. Agg. Md-45c (55%)	1526	lbs
Coarse Sand	Cs-186/Md-45c(32%)	884	lbs
Fine Sand:	Md-36c (13%)	329	lbs

Specific Gravity (SSD) Coarse:	2.531	Coarse sand:	2.517	Fine Sand:	2.53
Absorption (%) Coarse:	2.3	Coarse sand:	2.5	Fine Sand:	2.1

Admixtures:

Air*:	MB AE90		0.5	oz/yd
Water Reducer:	MB: Polyheed 1020		28	oz/yd
Lithium:	MB AsRx 30	100%	2.0	gal/yd
Super Plasticizer:	MB Glenium 3030		43	oz/yd
Retardant:	MB Delvo		43	oz/yd

*Air dosage must be adjusted to achieve air content.

Trial Batch Properties:

			Specification
Slump, inches:	5 1/2	(ASTM C-143)	3 - 7
Air Content, %:	5.5	(ASTM C-231)	4 - 8
Fresh Unit Weight, pcf:	137.4	(ASTM C-138)	
Concrete Temperature, °F	70	(ASTM C-1064)	60-80
Yield:	1.0	(ASTM C-138)	
Water/Cement Ratio:	0.37		0.4

Compressive Strength:

Age, Days	7	14	28*
Strength, psi	5890	7000	

* Average of 3 Cylinders

Reviewed By [signature]

IDAHO MONTANA NEVADA OREGON UTAH WASHINGTON WYOMING

9853 W Hackamore Drive, Boise, Idaho 83709 P 208.376.8200 F 208.376.8201

TOTAL P.01

District 5

4500 ITD Paving

	#	Material	Description	Amount		Based On
1 >>	0	~~BRIG-SND~~ Pokey Sand	FINE AGG	1,043.000	lb	0.000
2	1	POC-#57	COARSE AGG	1,260.000	lb	0.000
3	2	BRIG-#4 1.5 Rock	BRIG-#4	460.000	lb	0.000
4	3	DUR-I/II	CEMENT	584.000	lb	0.000
5	4	NAVAJO	FLYASH	145.000	lb	0.000
6	5	WATER	COLD WATER	34.000	gl	0.000
7	6	MICRO-AE	AIR	20.000	oz	0.000
8	7	P-200N	MR-WATER REDUCER	22.000	oz	0.000
9	8	DELVO	HYDRATION STABILIZER	25.000	oz	0.000
*						

APPENDIX-D: IMPLEMENTAION OF THE PCC DATABASE

Database screenshots for each mixture

GO BACK TO MAIN SCREEN

District 1, Structural Mixture

PCC

Unit weight (pcf)	142.9
Poisson's ratio	0.16

Thermal

PCC coefficient of thermal expansion (in./in./deg F x 10^-6)	4.83
PCC thermal conductivity (BTU/hr-ft-deg F)	1.25
PCC heat capacity (BTU/lb-deg F)	0.28

Mix

Cement type	Type I (1)
Cementitious material content (lb/yd^3)	611
Water to cement ratio	0.41
Aggregate type	Limestone (1)
PCC zero-stress temperature (deg F)	
Ultimate shrinkage (microstrain)	-173.333
Reversible shrinkage (%)	50
Time to develop 50% of ultimate shrinkage (days)	
Curing method	Wet Curing

Strength

Level 1: PCC strength and modulus

Time	Modulus of rupture (psi)	Elastic modulus (psi)	Split tensile strength (psi)
7-day	630	3.55E+06	410
14-day	655	3.80E+06	465
28-day	715	4.25E+06	490
90-day	730	4.55E+06	510
20-year/28-day	1.2	1.2	1.2

Level 2: PCC strength and modulus

Time	Compressive strength (psi)
7-day	4040
14-day	4630
28-day	4870
90-day	5270
20-year/28-day	1.35

Level 3: PCC strength and modulus

Time	Compressive strength (psi)	OR	Modulus of rupture (psi)
28-day	4870		715

Note: AASHOTWare ME Design requires only one value (Compressive strength or Modulus of rupture)

GO BACK TO MAIN SCREEN

District 1, Lookout Paving Mixture

PCC

Unit weight (pcf)	148.1
Poisson's ratio	0.14

Thermal

PCC coefficient of thermal expansion (in./in./deg F x 10^-6)	3.75
PCC thermal conductivity (BTU/hr-ft-deg F)	1.25
PCC heat capacity (BTU/lb-deg F)	0.28

Mix

Cement type	Type I (1)
Cementitious material content (lb/yd^3)	688
Water to cement ratio	0.35
Aggregate type	Limestone (1)
PCC zero-stress temperature (deg F)	
Ultimate shrinkage (microstrain)	-186.667
Reversible shrinkage (%)	50
Time to develop 50% of ultimate shrinkage (days)	
Curing method	Wet Curing

Strength

Level 1: PCC strength and modulus

Time	Modulus of rupture (psi)	Elastic modulus (psi)	Split tensile strength (psi)
7-day	750	3.85E+06	520
14-day	755	3.90E+06	505
28-day	895	4.15E+06	535
90-day	890	5.15E+06	645
20-year/28-day	1.2	1.2	1.2

Level 2: PCC strength and modulus

Time	Compressive strength (psi)
7-day	4830
14-day	5470
28-day	5510
90-day	6560
20-year/28-day	1.35

Level 3: PCC strength and modulus

Time	Compressive strength (psi)	OR	Modulus of rupture (psi)
28-day	5510		895

Note: AASHOTWare ME Design requires only one value (Compressive strength or Modulus of rupture)

GO BACK TO MAIN SCREEN

District 2, Thain Road Paving Mixture

PCC

Unit weight (pcf)	144.7
Poisson's ratio	0.19

Thermal

PCC coefficient of thermal expansion (in./in./deg F x 10^-6)	4.51
PCC thermal conductivity (BTU/hr-ft-deg F)	1.25
PCC heat capacity (BTU/lb-deg F)	0.28

Mix

Cement type	Type I (1)
Cementitious material content (lb/yd^3)	611
Water to cement ratio	0.40
Aggregate type	Limestone (1)
PCC zero-stress temperature (deg F)	
Ultimate shrinkage (microstrain)	-532.500
Reversible shrinkage (%)	50
Time to develop 50% of ultimate shrinkage (days)	
Curing method	Wet Curing

Strength

Level 1: PCC strength and modulus

Time	Modulus of rupture (psi)	Elastic modulus (psi)	Split tensile strength (psi)
7-day	595	3.30E+06	390
14-day	660	4.10E+06	475
28-day	785	3.70E+06	470
90-day	865	4.65E+06	575
20-year/28-day	1.2	1.2	1.2

Level 2: PCC strength and modulus

Time	Compressive strength (psi)
7-day	3760
14-day	5130
28-day	5160
90-day	5830
20-year/28-day	1.35

Level 3: PCC strength and modulus

Time	Compressive strength (psi)	OR	Modulus of rupture (psi)
28-day	5160		785

Note: AASHOTWare ME Design requires only one value (Compressive strength or Modulus of rupture)

GO BACK TO MAIN SCREEN

District 2, US-95 Race Creek Bridge

PCC

Unit weight (pcf)	145.6
Poisson's ratio	0.20

Thermal

PCC coefficient of thermal expansion (in./in./deg F x 10^-6)	5.38
PCC thermal conductivity (BTU/hr-ft-deg F)	1.25
PCC heat capacity (BTU/lb-deg F)	0.28

Mix

Cement type	Type I (1)
Cementitious material content (lb/yd^3)	625
Water to cement ratio	0.35
Aggregate type	Limestone (1)
PCC zero-stress temperature (deg F)	
Ultimate shrinkage (microstrain)	-448.333
Reversible shrinkage (%)	50
Time to develop 50% of ultimate shrinkage (days)	
Curing method	Wet Curing

Strength

Level 1: PCC strength and modulus

Time	Modulus of rupture (psi)	Elastic modulus (psi)	Split tensile strength (psi)
7-day	795	4.65E+06	510
14-day	785	4.35E+06	510
28-day	810	4.90E+06	545
90-day	895	5.50E+06	680
20-year/28-day	1.2	1.2	1.2

Level 2: PCC strength and modulus

Time	Compressive strength (psi)
7-day	5340
14-day	5610
28-day	6900
90-day	7560
20-year/28-day	1.35

Level 3: PCC strength and modulus

Time	Compressive strength (psi)	OR	Modulus of rupture (psi)
28-day	6900		810

Note: AASHOTWare ME Design requires only one value (Compressive strength or Modulus of rupture)

GO BACK TO MAIN SCREEN

DISTRICT 3 - I-84 Paving Mixture

PCC

Unit weight (pcf)	140.2
Poisson's ratio	0.15

Thermal

PCC coefficient of thermal expansion (in./in./deg F x 10^-6)	5.08
PCC thermal conductivity (BTU/hr-ft-deg F)	1.25
PCC heat capacity (BTU/lb-deg F)	0.28

Mix

Cement type	Type I (1)
Cementitious material content (lb/yd^3)	625
Water to cement ratio	0.36
Aggregate type	Limestone (1)
PCC zero-stress temperature (deg F)	
Ultimate shrinkage (microstrain)	-94.000
Reversible shrinkage (%)	50
Time to develop 50% of ultimate shrinkage (days)	
Curing method	Wet Curing

Strength

Level 1: PCC strength and modulus

Time	Modulus of rupture (psi)	Elastic modulus (psi)	Split tensile strength (psi)
7-day	650	2.75E+06	425
14-day	755	3.20E+06	440
28-day	745	3.60E+06	515
90-day	880	3.80E+06	600
20-year/28-day	1.2	1.2	1.2

Level 2: PCC strength and modulus

Time	Compressive strength (psi)
7-day	3890
14-day	4510
28-day	5590
90-day	6400
20-year/28-day	1.35

Level 3: PCC strength and modulus

Time	Compressive strength (psi)		Modulus of rupture (psi)
28-day	5590	**OR**	745

Note: AASHOTWare ME Design requires only one value (Compressive strength or Modulus of rupture)

GO BACK TO MAIN SCREEN

DISTRICT 5 - US-90 Paving Mixture

PCC

Unit weight (pcf)	140.2
Poisson's ratio	0.16

Thermal

PCC coefficient of thermal expansion (in./in./deg F x 10^-6)	
PCC thermal conductivity (BTU/hr-ft-deg F)	1.25
PCC heat capacity (BTU/lb-deg F)	0.28

Mix

Cement type	Type I (1)
Cementitious material content (lb/yd^3)	729
Water to cement ratio	0.34
Aggregate type	Limestone (1)
PCC zero-stress temperature (deg F)	
Ultimate shrinkage (microstrain)	-423.333
Reversible shrinkage (%)	50
Time to develop 50% of ultimate shrinkage (days)	
Curing method	Wet Curing

Strength

Level 1: PCC strength and modulus

Time	Modulus of rupture (psi)	Elastic modulus (psi)	Split tensile strength (psi)
7-day	655	4.05E+06	420
14-day	730	3.75E+06	435
28-day	775	4.30E+06	515
90-day	790	4.30E+06	575
20-year/28-day	1.2	1.2	1.2

Level 2: PCC strength and modulus

Time	Compressive strength (psi)
7-day	4540
14-day	4850
28-day	5080
90-day	5930
20-year/28-day	1.35

Level 3: PCC strength and modulus

Time	Compressive strength (psi)		Modulus of rupture (psi)
28-day	5080	OR	775

Note: AASHOTWare ME Design requires only one value (Compressive strength or Modulus of rupture)