USE OF HIGH PERFORMANCE CONCRETE IN OKLAHOMA BRIDGE DECKS

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The research consisted of two parts: a laboratory and a field investigation. The laboratory investigation consisted of an initial system of batching matrices and a succeeding empirical study to develop the four mixtures required. The field investigation consisted of test slabs for the HPC mixtures and actual bridge construction where the University of Oklahoma investigators served as consultants and additional tests were taken to further characterize the mixtures. Based on the results found in these investigations, conclusions and recommendations were made on the local materials and practices used in the HPC mixture.

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SI (METRIC) CONVERSION FACTORS

Approximate Conversions to SI Units					Approximate Conversions from SI Units				
Symbol	When you know	Multiply by	To Find	Symbol	Symbol	When you know	Multiply by	To Find	Symbol
		LENGTH					**LENGTH**		
in	inches	25.40	millimeters	mm	mm	millimeters	0.0394	inches	in
ft	feet	0.3048	meters	m	m	meters	3.281	feet	ft
yd	yards	0.9144	meters	m	m	meters	1.094	yards	yd
mi	miles	1.609	kilometers	km	km	kilometers	0.6214	miles	mi
		AREA					**AREA**		
in^2	square inches	645.2	square millimeters	mm	mm^2	square millimeters	0.00155	square inches	in^2
ft^2	square feet	0.0929	square meters	m^2	m^2	square meters	10.764	square feet	ft^2
yd^2	square yards	0.8361	square meters	m^2	m^2	square meters	1.196	square yards	yd^2
ac	acres	0.4047	hectares	ha	ha	hectares	2.471	acres	ac
mi^2	square miles	2.590	square kilometers	km^2	km^2	square kilometers	0.3861	square miles	mi^2
		VOLUME					**VOLUME**		
fl oz	fluid ounces	29.57	milliliters	mL	mL	milliliters	0.0338	fluid ounces	fl oz
gal	gallons	3.785	liters	L	L	liters	0.2642	gallons	gal
ft^3	cubic feet	0.0283	cubic meters	m^3	m^3	cubic meters	35.315	cubic feet	ft^3
yd^3	cubic yards	0.7645	cubic meters	m^3	m^3	cubic meters	1.308	cubic yards	yd^3
		MASS					**MASS**		
oz	ounces	28.35	grams	g	g	grams	0.0353	ounces	oz
lb	pounds	0.4536	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000 lb)	0.907	megagrams	Mg	Mg	megagrams	1.1023	short tons (2000 lb)	T
		TEMPERATURE (exact)					**TEMPERATURE (exact)**		
°F	degrees Fahrenheit	(°F-32)/1.8	degrees Celsius	°C	°C	degrees Celsius	9/5+32	degrees Fahrenheit	°F
		FORCE and PRESSURE or STRESS					**FORCE and PRESSURE or STRESS**		
lbf	poundforce	4.448	Newtons	N	N	Newtons	0.2248	poundforce	lbf
lbf/in^2	poundforce per square inch	6.895	kilopascals	kPa	kPa	kilopascals	0.1450	poundforce per square inch	lbf/in^2

Abstract

An investigation was performed to develop four different high performance concrete (HPC) mixtures for the Oklahoma Department of Transportation's (ODOT's) 2004 Innovative Bridge Research and Construction (IBRC) project funded by the Federal Highway Administration. These HPC mixtures are designed to achieve a greater durability than normal concretes with an emphasis on the shrinkage developed. These mixtures were developed by studying the affects of air entrainment, cementitious materials content, water to cementitious materials (w/cm) ratio, supplemental cementitious materials, fiber reinforcement, and a shrinkage-reducing admixture. Additionally, a large focus of this investigation was developed in the aggregate blend used in the concretes. This study was performed by conducting a separate study of the validity of the Shilstone method of blending aggregates.

The research consisted of two parts: a laboratory and a field investigation. The laboratory investigation consisted of an initial system of batching matrices and a succeeding empirical study to develop the four mixtures required. The field investigation consisted of test slabs for the HPC mixtures and actual bridge construction where the University of Oklahoma investigators served as consultants and additional tests were taken to further characterize the mixtures. Based on the results found in these investigations, conclusions and recommendations were made on the local materials and practices used in the HPC mixture.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1 – Introduction

1.1 Summary

Bridges are vital for everyday life in the United States. They allow us to keep the nations economy, emergency lines, and much more up and running. Today more than ever, these bridges are in need of immediate attention. The overwhelming amount of bridges that are classified as structurally obsolete or deficient continues to be a concern. This is a primary concern for the Oklahoma Department of Transportation (ODOT) since they contain a majority of these problematic bridges.

The Federal Highway Administration (FHWA) has developed a program known as the Innovative Bridge Research and Construction (IBRC) program. The IBRC was developed to promote new technology and methods of improving the United States bridges through performance, economics, and safety. In 2004, the state of Oklahoma was granted funding for research into high performance concrete (HPC) bridge deck mixes that will foremost improve the overall durability of the concrete with an emphasis on reducing the concrete shrinkage.

The investigation outlined in this thesis develops four HPC mixtures to be used in this project through the investigation of several concrete materials. This investigation primarily takes in consideration the aggregate blend used in the concrete by providing a side study of the Shilstone method of aggregate blending. This thesis documents the findings from a literature review, laboratory studies, field investigation, and actual bridge construction as well as provides conclusions and recommendations.

1.2 Objective of Research

The purpose of this research was to provide four HPC mixtures to be used in the 2004 Oklahoma IBRC bridge construction project with two of the four HPC mixtures to include reinforcing fibers. This was done by investigating several different local materials and admixtures of possible use. In addition, one of the main focuses of this HPC study lies in the aggregate blend of the concretes. This study was done by testing the validity of the Shilstone method of aggregate blending. At the conclusion of the laboratory studies, the actual bridge construction was performed with the mixtures where testing and observations were made in addition to consulting on field adaptations to the mixtures when necessary by the University of Oklahoma investigators.

1.3 Scope of Research

The variables that were studied in this investigation included: air-entrainment, cementitious materials content, aggregate blend, water to cementitious materials ratio (w/cm), supplemental cementitious materials, fiber reinforcement, a shrinkage-reducing admixture, and concrete temperature. This research investigates the aggregate blending through the use of percent retained charts, dry-rodded unit weights (DRUWs), and the Shilstone Coarseness Factor Chart.

Additionally, the shrinkage-reducer was tested to considerable extent for dosage rates and the timing of the additions.

To perform this research the fresh concrete properties of air content, slump, unit weight, DRUW, and concrete temperature as well as the ambient humidity and temperature were recorded. The hardened concrete properties of compressive strength, unrestrained length change, and modulus of elasticity were found for all of the batches. Additionally during the field test slabs the Air Void Analysis (AVA) was analyzed and at the bridge construction splitting tensile and freeze-thaw tests were performed.

CHAPTER 2 – Background

2.1 State of the Infrastructure

According to several recent studies, the need for the United States and especially Oklahoma, to improve the existing infrastructure is more important than ever. In 2005, the American Society of Civil Engineers (ASCE) published a progress report on the nation's infrastructure. According to ASCE, the United States earned a grade for bridges of C and an overall infrastructure grade of D. In addition, the Federal Highway Administration's (FHWA) 2005 National Bridge Inventory (NBI) states that approximately 156,177 bridges in the United States and 8,400 in Oklahoma are either structurally deficient or functionally obsolete. This means that approximately 26% of the nation's bridges are structurally deficient or functionally obsolete with over 5% of these being located in Oklahoma. A closer breakdown of the NBI data is presented in Table 2.1.

Table 2. 1 -- Deficient Bridges (FHWA 2003 NBI)

National Highway Systems and Non-National Highway Systems Combined							
Location	**Count**	**Structurally Deficient (SD)**	**% SD of count**	**Functionally Obsolete (FO)**	**% FO of count**	**Total Deficient (TD)**	**% TD of count**
Oklahoma	23,383	6,938	**29.67%**	1,462	**6.25%**	8,400	**35.92%**
United States *	594,616	75,871	**12.76%**	80,306	**13.51%**	156,177	**26.27%**

*United States count includes all 50 states as well as the District of Columbia and Puerto Rico. (FHWA, 2006)

A separate survey was conducted in 1996 with several departments of transportation. According to this survey, more than 100,000 bridge decks in the United States have suffered from early-age transverse cracking, which is a pattern that usually indicates drying shrinkage issues (Brown, 2003). With data like these and ODOT's experience, it easy to see the need for creating a concrete mix and/or construction practices that can withstand the shrinkage and cracking issues, producing a more durable bridge.

2.2 Innovative Bridge Research and Construction (IBRC)

The Federal Highway Administration (FHWA) has an active program titled the Innovative Bridge Research and Construction (IBRC) Program. This program has been set up to help state, county, and local bridge owners try innovative materials and materials technology in bridge projects. In turn, the program is intended to reduce the amount of congestion associated with bridge construction and maintenance projects, to increase productivity by lowering the life-cycle costs of bridges, to keep Americans and America's commerce moving, and to enhance safety (FHWA, 2006).

In the 2004 fiscal year, the state of Oklahoma received $225,000 in funding to be used in the I-40 over Business I-40 bridge reconstruction near Sayre, Oklahoma. A map of Oklahoma is supplied in Appendix A. The purpose of this proposed investigation is to aid the Oklahoma Department of Transportation (ODOT) in this project by performing the innovative research. This research entailed creating four (4) High Performance Concrete (HPC) mixtures to be used in four separate bridge spans during the construction process. The HPC mixtures were designed to reduce the amount of shrinkage normally seen in the typical concrete mixtures while still providing the appropriate properties such as the specified compressive strength and air content. This research was accomplished by focusing on the aggregate blends of the concretes and their effects on the desired parameters. To do this, the Shilstone method of blending aggregates was used. At the conclusion of the investigation, the final products were applied to full scale testing through the actual applications of the HPC mixtures in bridge construction.

2.3 High Performance Concrete (HPC)

The American Concrete Institute (ACI) defines HPC as “concrete meeting special combinations of performance and uniformity requirements that cannot always be achieved routinely using conventional constituents and normal mixing, placing and curing practices” (Freyne, 2005). HPC are specifically engineered to meet the particular performance criteria applications at hand. This can include a mixture to achieve optimum compressive strength, modulus of elasticity, durability, workability, or volume stability to name a few. Oklahoma’s 2004 IBRC project has several criteria that are requested for the mixture; however, its main focus is on shrinkage stability.

HPC is similar to conventional concrete in that they both primarily consist of the basic concrete constituents of cement, aggregates, and water. However, there is no specific equation for HPC mixtures and they are typically produced with one or more of the following: a low water/cementitious materials (w/cm) ratio, quality cement and aggregates, supplementary cementitious materials, and chemical admixtures (Freyne, 2005). These changes from a normal concrete to an HPC can create a wide range of difficulties that must be considered during the design and construction process including quality control of batching, fresh concrete workability, curing, reproducibility, and project specifications. The quality control can be affected by the variation of aggregate moisture contents in batching creating fluctuating amounts of water in the batches. Workability and cracking can be affected by issues such as the summer heat, amount and type of cement, as well as the admixtures used. These can require special measures to be taken for fresh concrete temperatures. Curing practices become more sensitive as well. This is due to the lack of excess water in most HPC mixtures, which in turn can cause surface cracks. To prevent this, moist curing is required as soon as possible with the minimum amount of the curing variable to each individual mix (Freyne, 2005). These issues are just a few that may be found when normal concrete batching is changed to an HPC mixture. In short, close attention in the total quality control should be paid to all the variables at hand.

In addition to the many variables that have to be closely governed, the unit cost of HPC compared to conventional concrete is often an issue. In general, it is true that HPC is more expensive and is more difficult to manage in the immediate application. However, HPC can be viewed as more economical when the cost analysis is viewed for the entire life cycle. This is due to factors such as the use of less material, reduced maintenance, and an extended service life. To achieve these benefits, the development of HPC must be attained at the local level due to the unique characteristics of the constituents used and the economic practicality of each. However, the combination of initial cost and the newness of HPC usage in the United States has led to a slow entrance into the local research market (Freyne, 2005).

2.4 Concrete Shrinkage

Volumetric changes in concrete are inevitable. Therefore efficient concrete design requires understanding the causes and nature of the changes. In the presence of no restraints, concrete shrinkage would be of little consequence. However, these contractions are usually restrained by its supports, an adjacent structure, and bonded reinforcement. All of these produce a gradually increasing tensile force on the concrete as it shrinks. Since concrete is relatively weak in tension but rather strong in compression, the added tensile stresses may lead to cracking, continuation of cracking, or increases in deflection (Kosmatka & Panarese, 1994). These issues pose an increasing threat on structures. In turn, with the lack of emphasis in codes and a lack of design for shrinkage, some believe that the problems tend to show up more often (Gilbert, 2001).

Cracking due to shrinkage has numerous variables such as the amount of restraint to shrinkage, the tension strength of the concrete, tensile creep, and the tension produced by load. In turn, the only way to avoid shrinkage effects is if the increasing tensile stress brought on by shrinkage, and reduced by creep, is always less than the tensile strength of the concrete. On the other hand, the concrete tensile strength generally increases with time along with the modulus of elasticity. This leads to the tensile stress from shrinkage increasing as well. On top of this, the relief brought by creep decreases with time and the existence of load induced tension in uncracked regions accelerates the formation of time-dependent cracking. Therefore, shrinkage cracking is usually to be expected (Gilbert, 2001).

The reason that shrinkage is a concern is that the volume change can lead to cracks in the structure. The cracks occur when connections develop between isolated microcracks, visible cracks, and pores. These cracks then allow corrosion of reinforcing steel and sulfate attack to develop when water and chloride ions are able to move inwards on the structure. These corrosive additions have their own negative effects such as additional cracking, spalling, and delamination of the concrete. In turn, the overall structural integrity and serviceability of the structure is lowered more rapidly through time.

2.4.1 Types of Concrete Shrinkage

Shrinkage of concrete is defined as the time-dependent measure of strain in an unloaded and unrestrained specimen (Gilbert, 2001), or more simply as the decrease in volume (Kosmatka & Panarese, 1994). This decrease in volume can be viewed even closer in four main sub-types. These include:

- **Plastic**
    - Caused by the loss of moisture prior to the setting of concrete (Mokarem, 2002)

- **Autogeneous**
    - Connected to the capillary pores losing water during the hydration of cement (Mokarem, 2002) or volume change due to the chemical reaction product being less than the volume of the reactants

- **Carbonation**
    - Results when, in the presence of carbon dioxide, the various cement hydration products carbonate (ACI, 209R-3)

- **Drying**
    - The volumetric change caused by drying after the setting of the concrete (Mokarem, 2002)

2.4.1.1 Plastic Shrinkage

Plastic shrinkage is produced with freshly mixed concrete when ambient conditions produce rapid evaporation of moisture from the concrete surface; thus, it is usually, but not exclusively, associated with hot-weather concreting or windy conditions. The cracks are produced when the water evaporates from the surface faster than it can appear at the surface during the bleeding process. The product of this process is rapid drying shrinkage and tensile stresses in the surface that results in short, irregular cracks often called “turkey tracks”. These cracks appear mostly on horizontal surfaces which lead to a concern for bridge decks. Evaporation causing environmental conditions of high ambient and concrete temperatures, low humidity, and high winds are some of the major factors in plastic shrinkage. Actions to reduce the effects can be taken during construction and curing such as wind and solar breaks, wetting of the aggregates, as well as fogging and covering the freshly poured concrete (Kosmatka & Panarese, 1994).

2.4.1.2 Autogeneous Shrinkage

Autogeneous shrinkage is especially an issue in concretes with a low w/cm and tends to increase with higher temperatures and cement contents. If in a mixture no additional water past the mixing water is added, there is the possibility of the concrete drying out even with no moisture being lost to the environment. This process is known as self-desiccation and is not dependent of whether the water is lost by physical or chemical processes. However, it is known that if the concrete is continuously cured under water a slight expansion will occur (Mindess & Young, 1981). Autogeneous shrinkage is common but harmful effects are most often seen in mass concrete. Since it is usually relatively minor it is not usually distinguished from shrinkage caused by drying (Mokarem, 2002).

2.4.1.3 Carbonation Shrinkage

Carbonation shrinkage is a phenomenon that is developed when carbon dioxide reacts chemically with hardened concrete. This risk is mostly seen at a relative humidity around 50% since humidity levels above this create pores mostly filled with water and reduce the penetration levels of the CO_2. Lower humidity levels hinder this process as well due to the decreased amount of water film. With concrete in this process, it acts much like normal drying shrinkage. It is believed that CO_2 reacts with C-S-H (calcium silicate hydrate) reducing the C/S

(CaO/SO_3) ratio. This carbonation of C-S-H has been seen to reduce the bonding of the materials and in turn could account for the irreversible shrinkage characteristics that developed (Mindess & Young, 1981). Due to the nature of this shrinkage, it is not predicted to be a major factor in this bridge research as it may be with a concrete to be used in a parking facility.

2.4.1.4 Drying Shrinkage

Drying shrinkage of hardened concrete is arguably the most important type of shrinkage. This form of shrinkage is associated with the contraction of the concrete due to the loss of capillary water (Kao, 2005). Since almost all concrete is developed with more water than is needed to hydrate the cement, most of what is left evaporates and causes the concrete to shrink. Concrete by nature expands slightly with an increase of moisture and contracts when moisture is lost. When restraints are applied to the concrete in addition to the contractions, internal stresses are created and eventually cracks after the tensile capacity is achieved (PCA, 2006). The shrinkage produced can be minimized with a better knowledge of the concrete properties but never eliminated; hence, shrinkage should be taken into consideration during design.

2.4.1.5 Additional Shrinkage Factor (Thermal)

Thermal effects can be viewed with concrete shrinkage as well. As the temperature rises in the center of the concrete, seen commonly during the heat of hydration of cementitious materials, the outside edges of the concrete may be cooling and contracting. This temperature gradient causes tensile stresses and eventually cracks if the gradient is too high. These thermal effects are worsened with an increase in section size and are especially significant in mass concrete (PCA, 2006)

2.5 Effects of Concrete Ingredients on Drying Shrinkage

- **w/cm**

The most important factor towards shrinkage is the w/cm. When the amount of water used is kept as low as possible the possibility of excessive shrinkage is lowered. The water can be minimized in a mixture by increasing the coarse aggregate and lowering the slump needed. However, this can become difficult when water requirements are increased for batching purposes of high slumps, concrete temperatures, and fine aggregate contents. According to a study at the Massachusetts Institute of Technology, a 1% increase in mixing water coincides to a 2% increase in shrinkage (Kosmatka & Panarese, 1994).

- **Cement**

It has been found in the past that the type of cement, cement fineness and composition, and cement content have relatively little affect on the drying shrinkage of normal-strength concrete (Kosmatka & Panarese, 1994). However, if the cement content is increased, then the w/cm, paste content, and aggregate content per volume of concrete is affected which can all have adverse affects on the concrete. The fineness of cement can also have possible affects on the volumetric change of the concrete due to a possible increase water demand for finer particles.

- **Aggregates**

The paste content affects the drying shrinkage of mortar more than that of the concrete. This is due to the aggregates in concrete physically restraining the shrinkage of the paste. The presence of aggregates alone is not the only factor. The actual type of aggregate plays an important role as well in drying shrinkage. The most desirable aggregates to use are those that are hard and rigid due to there incompressibility which makes them capable of providing more restraint against shrinkage in the paste. Aggregates with low drying shrinkage properties and minimal amount of clay are desirable as well. Some aggregates of choice are quartz, granite, feldspar, limestone, and dolomite (Kosmatka & Panarese, 1994).

- **Admixtures**

Some admixtures, none of which were used in this investigation, require an increase in water. These include accelerators such as calcium chloride which in turn increase shrinkage from the need for water. Other admixtures reduce the amount of water needed in the mixture but increase the shrinkage at the same time. The water-reducing admixtures that develop this usually contain an accelerator to counteract the retarding effects produced. Air-entrainers and some finely divided mineral admixtures, i.e. fly ash, have no significant effects on drying shrinkage (Kosmatka & Panarese, 1994). However, the entrained air content of the concrete produced has an effect on the concrete performance.

2.6 Aggregates

Due to materials, construction needs, and durability requirements, there is no method for selecting the best aggregate proportions for the best combined aggregate grading of a given project using local materials. Thus, performance objectives for individual projects should be analyzed. Some performance objectives are ease of placement, compaction without segregation, finishability, early strength, long-term mechanical properties, permeability, density, heat of hydration, toughness, volume stability, and a long life in service environments. The aggregate selection methods currently in use comply to the requirements of industry and public agency standards but can not assure the best performance (ACI 211-A, 2004).

2.6.1 Historical Development

The "water-cement ratio (w/c) law" for concrete proportioning, prepared by Professor Duff Abrams in 1919, is one of the first analytical concrete proportioning methods and is based upon the absolute volume of water to the loose volume of a sack of cement. According to this method, a mixture with 7.5 gallons of water to 1 sack of cement had a w/c of 1.00. This method was used until about the mid 1960's and is presently used with some adaptations. Now the ratio is measured in mass units and would be expressed as a w/c of 0.66 (ACI 211-A, 2004).

Abrams evaluated many different aggregate proportioning techniques available throughout his studies. From these investigations, he reported them all inadequate when attempting to correlate test data for aggregate blends from different sources. Abrams' claimed that these methods did not consider the grading of the aggregates and that the only way to obtain test data that could be correlated was to proportion the aggregates based upon a combined fineness modulus formula that he developed (ACI 211-A, 2004).

Due to Abrams' and other researchers' studies, an undated manual titled *Design and Control of Concrete Mixtures* was created by the Portland Cement Association (PCA). The first section of this manual was labeled "Water Ratio Theory". This theory was broken into three steps. The first of which was to create the optimum aggregate blend to reduce the amount water needed. The second step addresses the consistency or workability of the concrete by considering the project conditions, and the final step was the mix or the quantity of cement needed which was added at the appropriate w/c to produce the specified strength. Many in the industry today contradict this work of Abrams since it requires a selected w/c without any concern for the total water. The concept of choosing an optimum w/c required for strength leads to negative durability traits. One of these negative traits is shrinkage which is affected by the total water. It also does not take into consideration the use of partial cementitious material replacements which have become common. In 1927, the second edition of the *Design and Control of Concrete Mixtures* was issued. This edition's first section was changed to "Water-Cement Ratio Strength Law". This change was due to the comments on the importance of the control of the mixing water being recognized (ACI 211-A, 2004). After numerous amounts of research, it is now considered a "law" even though it does not consider the degree of hydration, the air content of concrete, or the effects of aggregates (Mindess & Young, 1981).

Aggregate grading standards have changed throughout the years. In the past, the American Society of Testing and Materials (ASTM) standard C33-23T stated that coarse particles should make up the majority of the fine aggregate. In contrast, today fine particles prevail and coarse aggregates have become coarser than was specified in the past. The standards in 1923, with finer coarse aggregates and coarser fine aggregates, allowed concrete producers to provide a durable concrete with a nice blend using only two aggregate bins. However, PCA recommended that the ASTM C33 should provide a stricter gradation with respect to the fine aggregates. This recommendation included only 65% of the fine aggregate to be allowed to pass the No. 8 sieve. The result of this change allowed the coarse and fine aggregate gradings to overlap assuring that their were sufficient amounts of aggregates passing the 3/8 in. sieve but retained on the No. 8 sieve (ACI 211-A, 2004).

In 1938, a concrete proportioning method known by “Goldbeck and Gray” was presented. This method provided a new way of selecting the aggregate blend to be used based on the dry-rodded unit weight (DRUW) of the coarse aggregate and the fineness modulus of the fine aggregate. This method simplified the procedures used in the past tremendously due to old methods requiring the DRUW for both coarse aggregates for each strength, slump, and maximum aggregate size (ACI 211-A, 2004).

Additional studies by Weymouth and Powers addressed issues of aggregate particle interference, clustering of adjacent sizes, and how gaps in gradation can lead to segregated mixtures. If segregation of aggregates in concrete is encountered, the concretes performance is hindered. When concrete is in the placing and finishing process of construction, segregation of the coarse aggregates and mortar is common. Thus from the findings of Weymouth, it was stated that the gradation of the aggregates is not what needed to be changed, but rather the missing particle sizes should be added to the blend to lessen the segregation affects (ACI 211-A, 2004).

In 1993, ASTM C33 provided a way to improve the particle blend of combined aggregates to remedy the gap-grading issues. The new specifications no longer required that the aggregates used had to meet gradation standards, since it was declared that the resulting blend was what was important. This allowed lower cost aggregates to be used as long as they met blend specifications in the final product. To make this possible some additional blend sizes had to be added to the specifications including Size 89 and finer Size 9 (ACI 211-A, 2004).

Additional investigations into aggregate proportioning were developed by Dr. James M. Shilstone, Sr., which has led to the main aggregate blending methods used in this investigation performed at the University of Oklahoma. Shilstone was an acting consultant for a project in Saudi Arabia when he found that they had no concrete aggregate standards. As an acting consultant, Shilstone was set to create the design objectives for the project at hand and to develop the project concrete specifications. For the project, Shilstone sent the available local aggregates to Athens, Greece. There a series of concrete batches were made with varying aggregate blends. In addition, water contents were adjusted to produce the desired slump but all other variables were constant. These batches were tested for the plastic concrete properties, strength, and for their response to vibration using a vibrator (ACI 211-1, 2004).

Shilstone found in the end that one batch out performed all of the others in all of the categories. This batch backed up the studies performed by Weymouth for a well-graded combined aggregate blend. Shilstone decided to combine three aggregates instead of two to get the gradation desired. The three aggregates provide a particle distribution in the areas deemed necessary for a well graded mix. These aggregate particle breakdowns are classified as coarse (plus 3/8 in. sieve), intermediate (between 3/8 in. and No. 8 sieves), and fine (minus No. 8

sieve). The concrete batch that Shilstone chose had a blend where the intermediate particles filled the major voids between and around the large particles. The fine aggregate and paste then filled the remaining voids to produce a mixture with the least water content (ACI 211-A, 2004).

Shilstone backed his findings in Saudi Arabia with investigations of high and low performing mixtures in the United States. He then went on to apply his finding to software that has been used by many in the concrete industry. Through this program, more information became available and concrete producers found definite improvements in the quality of their mixtures. It was found that from the reduced water content needed due to the optimized blend that the mixtures are more cohesive which prevents segregation and facilitates pump applications and finishing (ACI 211-A, 2004).

2.6.2 Shilstone Method

The purpose of this section is to provide an explanation of the concrete proportioning method developed by Dr. James M. Shilstone, Sr. It provides a quantitative method for optimizing aggregate proportions and making adjustments during the process of construction. Shilstone believes that this method can improve the overall quality of concrete due to the current practice is usually changed on a post-quantitative measure, i.e. optimization is conducted during construction by adding a bag of cement or just adding high-range water-reducers. The scope of his research was conducted over a fifteen year period and was performed using rounded cubical aggregates and ASTM C 494, type A or D admixtures (Shilstone, 1990).

The Shilstone method is based on three factors to optimize the aggregate characteristics at hand. These factors include the relationship between the coarseness of the two larger aggregate fractions and the fine fraction, the total amount of mortar, and the aggregate particle distribution (Shilstone, 1990). As briefly noted in the historical development section, Shilstone concluded several factors from his studies. These include (Shilstone, 1990):

- The current establishment of mixtures by weight contributes to problems from variable aggregates and construction needs.

- The method of selecting the proportions is irrelevant. The characteristics of the concrete are the important factors.

- When a combination of materials has been found, this composite and adjustment procedures can be turned into a mathematical and graphic model as a mixture design. A mixture design may be able to be adapted worldwide and used indefinitely as long as aggregates characteristics are similar except for gradation and specific gravity.
- The concrete producer’s solution to the design is the proportions. This allows quality production with the available resources and the lowest cost.

- The current ASTM and governing aggregate specifications do not provide the best concrete due to a lack of emphasis on the blends. Aggregate not meeting ASTM C33 can still be used as long as a well-graded blend is produced.

- Construction needs are to be considered second only to engineering criteria in selecting the mixture design.

The objective to a quality mixture is simple. Shilstone explains the packing ratio concept through a stone wall example. A mason decides on how much mortar to use by the size of stones being used. If the stones are all of the same size, the mason will need to use more mortar to fill the voids in between each stone. However, if smaller stones are introduced as well, the mason can fill some of the voids with the smaller stones and use less mortar. This is the same basic concept of the aggregate blend in concrete. If a gap graded blend is used more mortar will be needed to coat the aggregates and fill the voids. This leads to a decrease in concrete performance and constructability. On the other hand, if intermediate particle sizes are introduced the concrete will perform better overall.

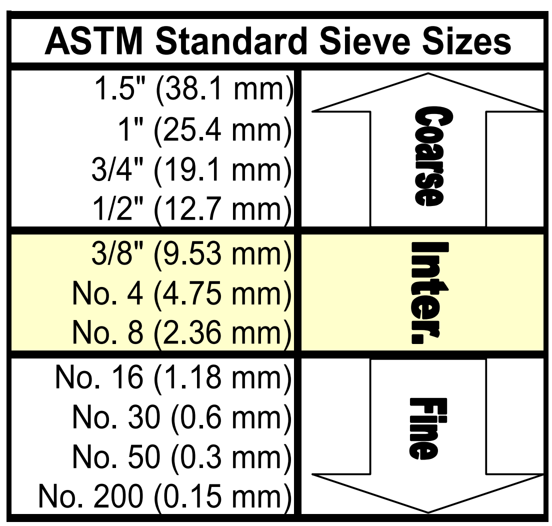
Shilstone states that the current concrete practices are "wasteful and contribute to many industry problems such as unnecessarily high costs, poor construction productivity, and reduced durability in the infrastructure". He then adds that "It is an attempt to direct attention to performance practices and concrete out-put rather than in-put." and that the concrete producer just needs to "prequalify the mixtures, identify those to be used, and provide statistical performance data" so that it is possible to stop offering new mix designs for every project. Through the use of Shilstone's three factors (Coarseness Factor, Mortar Factor, and Aggregate Particle Distribution) this is believed to be feasible (Shilstone, 1990). The following sections explain each of these factors.

2.6.2.1 Coarseness Factor Chart

The goal of a quality mixture is to fill the voids with a quality, inert filler instead of an increase in binder. It is known that as coarse aggregate becomes finer, the sand is needed to be finer to fill the voids; however, as sand becomes finer it should be reduced. This knowledge generically characterizes sand due to the variations in particle sizes from source to source. It is possible to have as much as 20 percent and as little as 0 percent of sand pass the 3/8 in. (9.5 mm) sieve and be retained on the No. 8 (2.36 mm) sieve. Instead of looking at the aggregate alone, Shilstone believes that these sizes and those that correspond from the coarse aggregate should be classified as intermediate particles. In turn the aggregates should be separated by particle sizes and not the by the aggregate stockpiles. This focus on the intermediate particles can create a better filling of the void spaces with sound particles (Shilstone, 1990).

Shilstone qualifies the aggregate particle sizes as coarse (retained on 3/8 in (9.5 mm) sieve), intermediate (passing 3/8 in. (9.5 mm) sieve and retained the No. 8 (2.36 mm) sieve), and fine (passing the No. 8 (2.36 mm) sieve). Figure 2.1 presents this particle breakdown graphically. The coarse aggregates are considered the high quality inert filler sizes. This is due to there ability to reduce the need for mortar which shrinks and cracks. The intermediate particles are used to fill major voids and aid in the mixtures mobility. However, if sharp or elongated aggregates are used a mixture may be created with more harsh workability characteristics. The fine particles are there for workability. These particles work in a way close to ball bearings that allow the mixture to flow much easier (Shilstone, 1990).

Figure 2. 1 – Aggregate Particle Size Classification



From Shilstone's studies, it was found that the total amount of fine sand required to create an optimum mixture is related to the relationship between the two larger aggregates. This led Shilstone to create his relationship of the amount needed of each aggregate. These relationships were defined as the Coarseness and Workability Factors. Figure 2.2 displays this method graphically. Where the Coarseness Factor is plotted on the x-axis and is found as:

$$\textbf{Coarseness Factor} = \frac{\text{coarse}}{\text{sum of coarse and intermediate}} \times 100$$

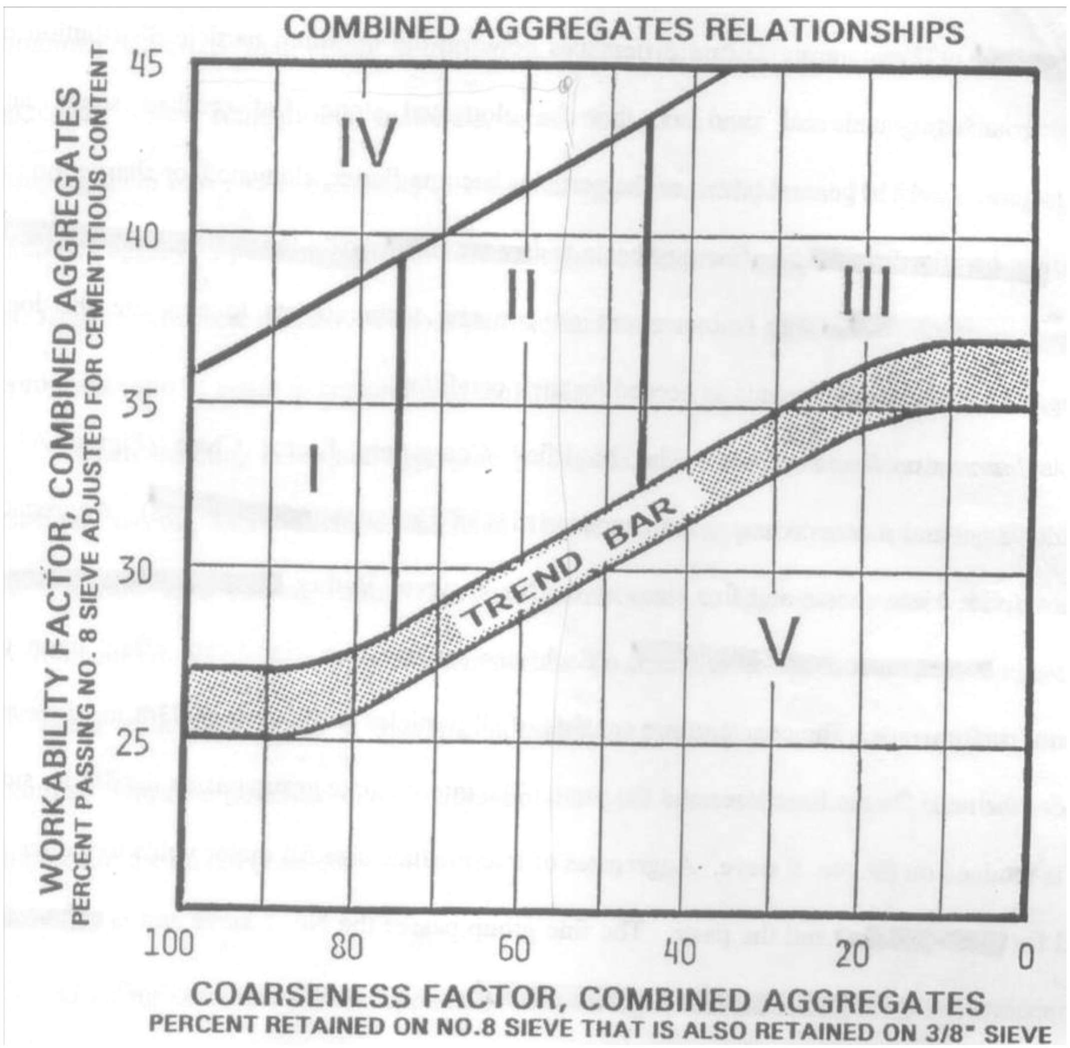
$$= \frac{\text{mass retained on 3/8 in sieve and larger}}{\text{mass retained on the No. 8 sieve and larger}} \times 100$$

The y-axis is governed by the Workability Factor and is found as the percent of combined aggregates passing the No. 8 sieve. Shilstone states that an adjustment factor may apply to the Workability Factor due to the amount of cementitious material. From his research, starting at a cementitious materials content of 564 lb/yd^3 (335 kg/m^3) [6 U.S. 94 lb (42.6 kg) bags] an adjustment of 2.5 for each additional bag in excess should be made to the Workability Factor and vice versa if less (Shilstone, 1990).

In Figure 2.2, the zones identify regions where the factors of the aggregate blends likely produce certain characteristics based upon field experience. The diagonal trend bar displays a region where combined rounded or cubical crushed stone and well-graded natural sand are in balance. However, such mixtures have limited application since the grading must be well controlled. The mixtures found here are often well suited for bucket placed concrete (ACI 211-A, 2004).

The mixtures above the trend bar are usually considered too sandy and can create a mixture that is “sticky” and has a higher water demand. The mixtures below the trend bare are, in contrast, usually rocky and create a mixture that is “bony” (Shilstone, 1990).

Figure 2. 2 – Coarseness Factor Chart (ACI 211-A, 2004)



The zones on the chart have been found through research to classify mixtures with the following properties (ACI 211-A, 2004):

- **Zone I**

  Mixtures are typically gap-graded and have a high potential for segregation due to lack of intermediate particles.

- **Zone II**

  This zone exhibits the optimum mixture with maximum nominal aggregate size from 1 ½ in (37.5 mm) through ¾ in (19.0 mm). Those mixtures in this zone that plot close to the trend bar or near Zones I, IV, and V require close control.

- **Zone III**

  Optimum mixture for aggregate sizes for maximum nominal aggregate sizes smaller than ¾ in (19.0 mm).

- **Zone IV**

  This zone exhibits mixtures with excessive fines and a high potential for segregation.

- **Zone V**

  This zone indicates mixtures which are too coarse and non-plastic.

2.6.2.2 Mortar Factor

The Mortar Factor is an extension of the Coarseness Factor Chart. The mortar in concrete is found by the sum of the combined aggregate passing the No. 8 (2.36 mm) sieve plus the paste consisting of cementitious materials, water, and air. The amount of mortar needed varies for construction purposes to facilitate placement and compaction purposes. The amount required is dependent on factors such as the aggregate particle shape and texture as well as the maximum aggregate size (ACI 211-A, 2004).

There are sum issues involved in the calculation of the mortar content. These include heavy influences from water and entrained air. Shilstone states that an entrained air tolerance of ±1% of the volume is the equivalent of allowing the volume of water to vary slightly more than 33 lb/yd^3 (20 kg/m^3). This affect can vary the mortar content by 0.02% and create many problems. Additionally, the water demand varies with the entrained air variation creating a problem with the two combined (Shilstone, 1990).

Another issue with the mortar factor is that of the type of construction. Different methods of concrete application will require different mortar contents. Shilstone has provided guidelines for ten different construction classifications as follows (Shilstone, 1990):

- **Class 1 = 48 to 50 %**

  Placed by steep sided bottom-drop bucket, conveyor, or paving machine.
- **Class 2 = 50 to 52 %**

  Placed by bottom-drop bucket or chute in open vertical construction.
- **Class 3 = 51 to 53 %**

  Placed by chute, buggy, or conveyor in an 8 in (200 mm) or deeper slab.

- **Class 4 = 52 to 54 %**

  Placed by 5 in (125 mm) or larger pump for use in vertical construction, thick flat slabs and larger walls, beams, and similar elements.

- **Class 5 = 53 to 55 %**

  Place by 5 in (125 mm) pump for pan joist slabs, thin or small castings, and high reinforcing steel density.

- **Class 6 = 55 to 57 %**

  Place with a 4 in (100 mm) pump.

- **Class 7 = 56 to 58 %**

  Long cast-in-place piling shells.

- **Class 8 = 58 to 60 %**

  Placed by pump smaller than 4 in (100 mm).

- **Class 9 = 60 to 62 %**

  Less than 3 in (75 mm) thick toppings.

- **Class 10 = 63 to 66 %**

  Flowing fill.

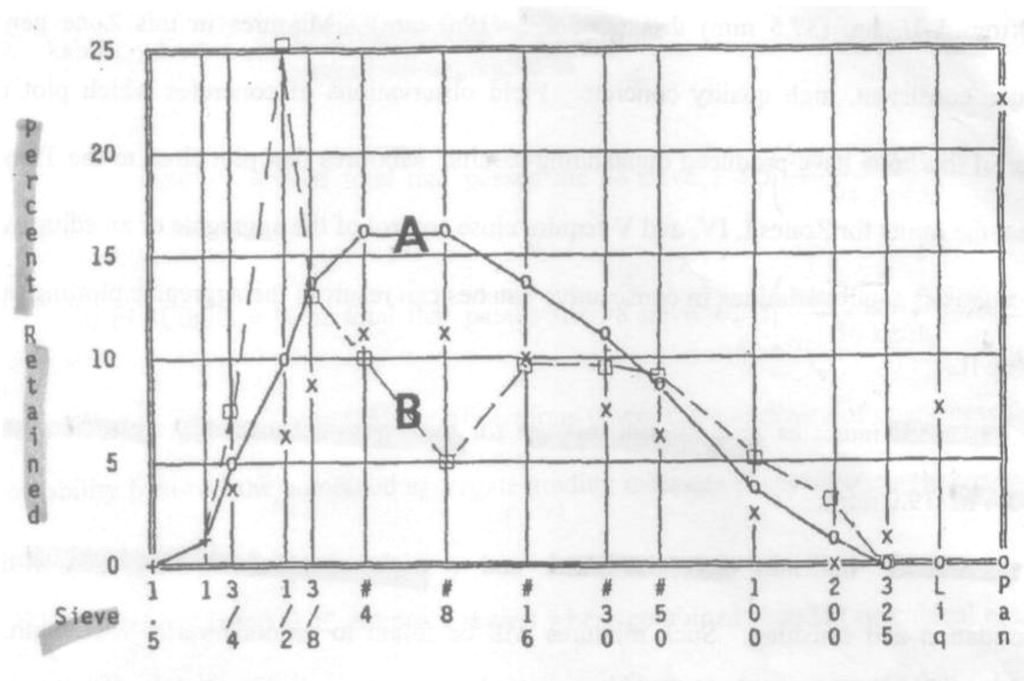
The cost of concrete placement is considerable in construction practices. Thus, an examination of which mortar content is to be use should be made. To maintain the w/cm, the total cementitious materials factors will vary with the mortar content. This means that higher mortar content mixtures will cost more than lower content mixtures. However, a low mortar content mixture may affect the time of completion and raise cost. A case-by-case examination should be made for this consideration (Shilstone, 1990).

2.6.2.3 Aggregate Particle Distribution

Almost any concrete mixture can be designed to produce a given strength. However, the constructability and long term serviceability can be affected if a poor distribution of particle sizes is present. An optimum combined aggregate particle distribution is well-graded and contains no gaps in the intermediate particle sizes (Shilstone, 1990).

In Figure 2.3, plot B represents a typical ASTM C 33 size #57 stone and concrete sand blend used in a mixture. Even with a deficiency in intermediate particles passing the 3/8 in sieve, this single size stone and sand blend meets the specification standards; however, the mixture will have finishing problems even with a reasonable mortar content. If the sand is increased to satisfy the finishing issues, then the strength will be affected due to a higher water demand. In turn, the over mortared mixture can cause problems if the concrete is pumped due to an increase in friction. In contrast, Plot A shows a mixture that was produced with an addition of pea gravel. It can be seen that an ideal solution to the gradation is found by adding the intermediate size particles. However, it should be noted that it is usually very difficult to achieve a curve as perfect as this due to the stockpiles of the local aggregates; although, a better blend than with the two aggregate is easily achieved when paying attention to the composite blend and not the stockpiles as in Plot B (Shilstone, 1990).

Figure 2. 3 – Percent Retained Chart (ACI 211-A, 2004)



CHAPTER 3 -- Research Program and Procedures

3.1 Introduction

A research program was developed and implemented at The University of Oklahoma in conjunction with the Oklahoma Department of Transportation (1) to identify local materials to western Oklahoma and neighboring states that are suitable for generating HPC, and; (2) to create mixture proportions for four different HPC mixtures to be used in bridge decks. To accomplish these, two levels of testing were performed. The first consisted of initial matrices which were tested for primary objectives. Those mixtures that displayed the most desirable results moved on to the second level where they were adjusted for traits sought-after in actual construction. Table 3.1 lists the tests and the ASTM standard that is associated with each.

Table 3. 1 – Tests Performed

Primary Objectives	
Test	**ASTM Number**
Compressive Strength	C 39
Unrestrained Length Change	C 490
Air Content	C 231
Unit Weight	C 138
Dry-Rodded Unit Weight	C 29
Workability	---
Secondary Objectives	
Slump	C 143
Concrete Temperature	C 1064
Additional Testing	
Modulus of Elasticity	C 469
Splitting Tensile	C 496
Freeze Thaw	C 666

Air Void Analysis	---

3.2 Variables

A number of variables were present in the development of the mixtures. A system of matrices was used to evaluate the materials and to optimize the initial trial batches. In doing this, certain mixture variables were examined one at a time while maintaining all others constant. Variables examined in this manner are as follows:

- Air Entrainment -- MB AE™ 90 by Degussa Admixtures, Inc.
- Cementitious Materials Content
- Aggregate Blend
- Water/Cementitious Material Ratio (w/cm)
- Supplemental Cementitious Materials – replacement rates and combinations
- Fiber Reinforcement
- Shrinkage-Reducing Admixture -- Tetraguard® AS20 by Degussa Admixtures, Inc.
- Batching Temperature

Due to the number of variables, a vast amount of time went into comparing the affects of each. This led to over 45 batches performed. In turn, these batches produced over 675 cylinders and 140 length change prisms. The batching matrices can be seen in Section 3.3.1.

3.2.1 Cementitious Materials

The first step of the research began by obtaining the cementitious materials to be used. The materials were obtained from the Dolese Brothers plant in Yukon, Oklahoma to closely represent those readily available in the target construction area of western Oklahoma. This investigation focused on studying optimal amounts and combinations of the materials rather than the affects of different manufacturers. This was due to the need for the selected mixes to be used in future construction which leads to availability and economic issues. As seen in Table 3.2, these materials consisted of fly ash, slag, and Type II Portland cement. The evaluation and comparison of each mixture was based on a combination of workability, compressive strength, and unrestrained length change. Results and analysis of this study are presented in Chapters 4 and 5.

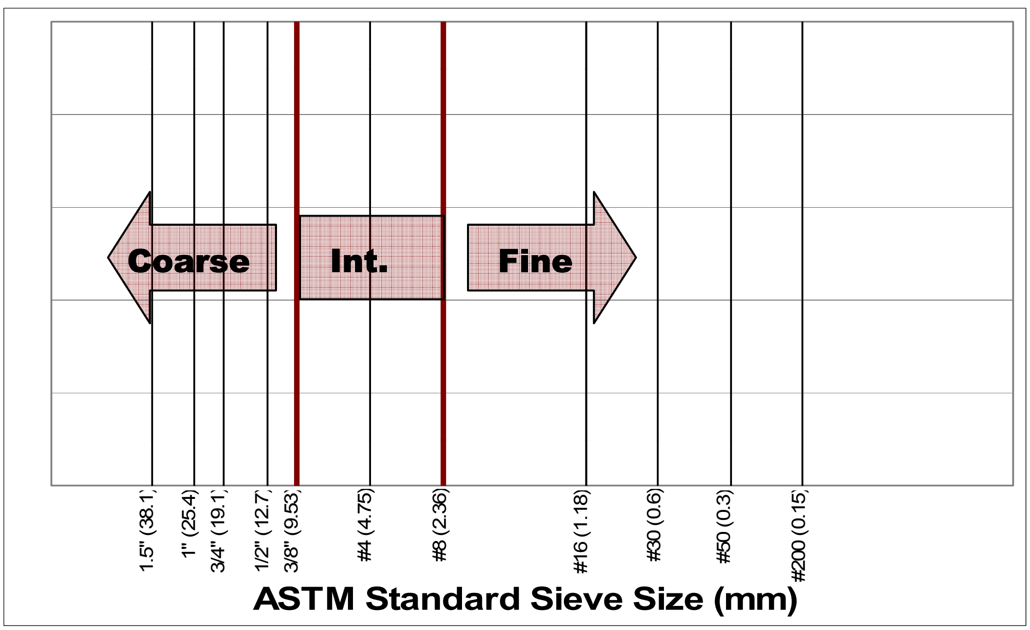
Table 3. 2 – Types of Cementitious Materials

Cementitious Materials		
Type	**Manufacturer**	**Plant Location**
Fly Ash	LaFarge	Amarillo, Texas
Slag	LaFarge	From Chicago, Shipped from Missouri
Type II Portland Cement	Ash Grove	Chanute, Kansas

3.2.2 Aggregates

Two coarse aggregates, an intermediate aggregate, and a fine aggregate currently used at local western Oklahoma batching sites were selected for the this investigation. The aggregates, like the cementitious materials, were obtained from the Dolese Brothers batch plant in Yukon, Oklahoma. These aggregates were designated coarse, intermediate, and fine according to common practice stated by Dr. James M. Shilstone, Sr. (Shilstone, 1990). Where the nominal particle sizes are as follows: coarse aggregates, above the 3/8 inch (9.5 mm) sieve; intermediate, between the 3/8 in. (9.5 mm) and No. 8 (2.36 mm) sieves; and fine, below the No. 8 (2.36 mm) sieve. These designations can be seen graphically in Figure 3.1.

Figure 3. 1 – Classification of Coarse, Intermediate, and Fine Aggregates



The coarse aggregates were graded by the supplier as #57 and #2 while the intermediate aggregate was designated as a 3/8 inch chip. These aggregates all consist of limestone from the Dolese Bros. quarry located in Cooperton, Oklahoma. The fine aggregate used was a quartz sand from the Kline Materials quarry located at Camargo, Oklahoma. Two separate aggregates were used at the beginning of the investigation for preliminary batches. These aggregates consisted of a #57 coarse limestone aggregate from the Richardson Spur quarry near Lawton, Oklahoma and a quartz sand from the Dover quarry in Dover, Oklahoma. Both of which were obtained from the Dolese Brothers batch plant in Norman, Oklahoma. The types of aggregates used in this investigation are presented in Table 3.3.

Table 3. 3 – Types of Aggregates

Aggregates		
	Type	**Quarry Location**
#57	Limestone	Cooperton, Oklahoma
#2	Limestone	Cooperton, Oklahoma
3/8 inch chip	Limestone	Cooperton, Oklahoma
sand	Quartz	Camargo, Oklahoma
Preliminary Aggregates		
#57	Limestone	Lawton, Oklahoma
sand	Quartz	Dover, Oklahoma

As was done with the cementitious materials, the aggregates were assessed in mixtures to determine their suitability for HPC production. Before testing could begin, a sieve analysis, according to ASTM C 136, was performed. This was carried out to compare the actual gradation to the gradations provided by the supplier in order to achieve a more precise distribution of the materials. The sieving was performed on a Gilson Test-Master® mechanical shaker, Serial No. 2243, Model No. TM-4 and a Rainhart Company laboratory sifter, Cat. No. 637. The resulting aggregate gradations are presented in Section 4.2.4.1.

To create the aggregate blends necessary for the HPC mixtures in this study. The aggregate blending method referred to as the Shilstone method was used. An explanation of the Shilstone method may be found in Section 2.6.2. These mixtures were all evaluated and compared in the areas of workability, compressive strength, dry-rodded unit weight, and unrestrained length change. Results of this study are presented in Chapter 4.

3.2.3 Admixtures

Several different types of admixtures were used in this investigation. These include admixtures for air entrainment, mid-range water reduction, and shrinkage reduction. The admixtures used in this investigation are presented in Table 3.4. The air-entrainer and water-reducer were used in each batch due to existing concrete practices in the area. These practices serve to meet guidelines set by ODOT for minimum air contents and workability levels. The air-entrainer and water-reducer in this study were MB AE™ 90 and Polyheed® 1020, respectively. Both of which are manufactured by Degussa Admixtures, Incorporated. Additional studies went into testing Degussa’s shrinkage-reducing admixture Tetraguard® AS20. A combination of workability, compressive strength, air content, slump, and unrestrained length change were used to evaluate and compare each mixture. Data sheets for each admixture are presented in Appendix B.

Table 3. 4 – Types of Admixtures

Admixtures		
	Type	**Manufacturer**
MB AE™ 90	Air-Entrainer	Degussa Admixtures, Inc.
Polyheed® 1020	Mid-Range Water Reducer	Degussa Admixtures, Inc.
Tetraguard® AS20	Shrinkage-Reducer	Degussa Admixtures, Inc.

3.3 Mix Design Development®

The materials identified in the sections of Cement (Section 3.2.1), Aggregates (Section 3.2.2), and Admixtures (Section 3.2.3) as well as Fibermesh ½" Stealth polypropylene fibers were used in the development of the mix designs. The designs were performed using a series of matrices to study the affects of the variables listed in Section 3.2 individually while holding all others constant. The primary investigation matrices for each variable were performed in the following order: Air-Entrainment, Cementitious Materials Content, Aggregate Blend, Water to Cementitious Material Ratio (w/cm), Supplemental Cementitious Materials Content, Fibers, and Shrinkage-Reducing Admixture. These were followed in a progressive manner (i.e. the desirable mix proportioning for each variable was held constant for the next matrix and so on). The matrices associated with each are presented in Section 3.3.1.

After the primary investigation matrices were completed, additional batching was performed to create mixtures with the desired properties. This secondary batching did not include a controlled matrix. The development was controlled by an empirical process. The air-entrainer, mid-range water-reducer, and shrinkage-reducer were varied along with the amount of ice added to the mixing water. This allowed the researchers to adjust the slump, air content, temperature, and compressive strength to the desired ranges while acquiring a lower length change than obtained by conventional concretes. The goal mix characteristics for this investigation are presented in Table 3.5.

Table 3. 5 – Mixture Goal Criteria for the Investigation

Mixture Goals	
Air Content	6 - 8%
Compressive Strength	>4000psi
Volumetric Change (shrinkage)	low
Slump	1-3 inches
Concrete Temperature	~75^{o}

The preliminary matrix batch proportions for the investigation were designed under the direction of Dr. Seamus Freyne, who at the beginning of researching worked for ODOT and is currently with the University of Manhattan. The actual mix designs for each batch are presented in Chapter 4.

3.3.1 Sequence of Investigation

The process of batching in this investigation is outlined in Tables 3.6-12 at the end of this section. These tables consist of seven batching matrices as well as schedules for typical mixes, secondary batching, and final batching. Each is broken down into batch numbers, a data page reference, and the necessary information to distinguish between the batches. The provided batch number is a chronological numbering system of all the batches performed. This numbering system was used throughout the investigation to designate the individual batches and as a tracking system for the specimens in the curing process. It may be noticed that some batches were used in multiple matrices for different study focuses. The data page column of the tables has been placed for quick reference. These refer to the pages in the appendices where data for each batch may be found.

The progressive approach used in this investigation is seen in the chronological order of the tables. For example, the affects of air content were tested in Matrix 1 which was then carried into Matrix 2 for cementitious materials content studies and so on. After the matrices were studied, the investigation then went into the mentioned empirical process. This process is represented in the Secondary Batching table. When the adjustments were made in the Secondary Batching, the Final Batching schedule was created.

The tables are designed to display the order and thought process behind the development of the investigation. To more fully understand their meaning a quick explanation is warranted. Each table contains the batch number and a data reference as explained earlier; however, the batch distinguishing information varies in format from table to table. For Matrices 1, 2, 4, 6, and 7, the format is the same. They each display the quantity of the variable in question. This allows the distinction between each batch to be easily seen. Matrices 3 and 5 display the necessary distinguishing information in percentage form. These are the percent of distribution of aggregates and cementitious materials of the total aggregate content and cementitious materials, respectively.

The remaining tables are laid out in a different manner. The Preliminary and Secondary Batching schedules are laid out to present the batches and data reference only. The changes from batch to batch are more fully outlined in Chapter 4. The Final Batches tables are designed in the same fashion as the typical and secondary with an additional feature. Since the goal of this investigation was to create four HPC mixtures, these are distinguished in the Mix Specifics columns of the tables.

Table 3. 6 – Mixture Schedule (Preliminary Batches)

Preliminary Batches	
Batch #	**Data Page**
1	C – 1
2	C - 2

Table 3. 7 – Mixture Schedule (Matrix 1)

Matrix 1 -- Air Content		
Batch #	**Air-Entrainer (MB AE™90) fl oz/cwt (mL/kg)**	**Data Page**
3	3.4 (2.0)	C – 3
4	0.0 (0.0)	C - 4

Table 3. 8 – Mixture Schedule (Matrix 2)

Matrix 2 -- Cementitious Materials Content		
Batch #	**80% Cement & 20% Fly Ash lb/cy (kg/m^3)**	**Data Page**
3	640.5 (380)	C – 3
5	606.8 (360)	C – 5
6	573.1 (340)	C – 6
7	539.4 (320)	C - 7

Table 3. 9 – Mixture Schedule (Matrix 3)

Matrix 3 -- Aggregate Blend					
Batch #	***Coarse***		***Intermediate***	***Fine***	**Data Page**
	#57	**#2**	**3/8" chip**	**sand**	
6	37%	---	24%	39%	C – 6
8	35%	26%	---	39%	C – 8
9	25%	---	37%	38%	C – 9
10	43%	---	27%	30%	C – 10
11	20%	41%	---	39%	C – 11
12	15%	40%	---	45%	C – 12
13	35%	---	19%	46%	C – 13
14	26%	---	30%	44%	C – 14
15	32%	---	27%	41%	C – 15
20	15%	37%	---	48%	C – 20
21	41%	---	11%	48%	C – 21
25	Sieves combined for optimum gradation				C – 25

Table 3. 10 – Mixture Schedule (Matrix 4)

Matrix 4 -- Water to Cementitious Materials Ratio		
Batch #	**w/cm**	**Data Page**
15	0.38	C -15
16	0.40	C -16
17	0.42	C - 17

Table 3. 11 – Mixture Schedule (Matrix 5)

Matrix 5 -- Supplemental Cementitious Materials				
Batch #	**Cement**	**Fly Ash**	**Slag**	**Data Page**
16	80%	20%	---	C – 16
18	50%	---	50%	C – 18
19	50%	20%	30%	C – 19
22	100%	---	---	C – 22

Table 3. 12 – Mixture Schedule (Matrix 6)

Matrix 6 -- Fibers		
Batch #	**Fibermesh 1/2" Stealth Fibers lb/cy (kg/m^3)**	**Data Page**
21	0.0 (0.0)	C – 21
23	5.1 (3.0)	C – 23

Table 3. 13 – Mixture Schedule (Matrix 7)

Matrix 7 -- Shrinkage-Reducer		
Batch #	**Degussa Admixtures, Inc. Tetraguard® AS20 fl oz/yd^3 (L/m^3)**	**Data Page**
21	0.0 (0.0)	C – 21
24	155.1 (6.0)	C – 24

Table 3. 14 – Mixture Schedule (Secondary Batching)

Secondary Batching Trial and Error Procedure (air content, slump, compressive strength)	
Batch #	**Data Page**
26	C – 26
27	C – 27
28	C – 28
29	C – 29
30	C – 30
31	C – 31
32	C – 32
34	C – 33
35	C – 34
36	C – 35
37	C – 36
38	C – 37
39	C – 38

Table 3. 15 – Mixture Schedule (Final Batches)

Final Batches		
Batch #	**Mix Specifics**	**Data Page**
40	cement + fly ash	C – 39
41	cement only	C – 40
42	cement + fibers	C – 41
43	cement + fly ash + fibers	C – 42
44	cement + fly ash (extended mixing time)	C - 43

3.4 Batch and Curing Procedures

Careful attention was paid to the batching and curing procedures due to the sensitivity of HPC and the number of variables present. All the materials used in batching were stored in doors at a constant temperature. The aggregates were kept in separate bins which in turn provided low moisture contents. The cementitious materials were all kept in plastic lined barrels and sealed. The barrels were then covered with plastic in order to limit contamination and moisture that can affect the hydration process.

After the primary investigation mixtures were tested, the aggregates were moved to a climate controlled eco-chamber for the second level of mixes. This change aided in developing lower concrete temperatures required in this study by ODOT. Additional steps for temperature control included using ice as a partial substitute for approximately half of the mass of water needed in the batches.

3.4.1 Batching Procedures

Throughout the batching process, ASTM C 192 (ASTM 1995) “Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory” was followed or modified to make researching achievable. The concrete mixer used in this research was a portable Stone®, Model 65CM, Serial #340032, 6 cubic foot electric power driven revolving mixer. The loading of the mixer was held consistent. This started with the wetting down of the inside of the drum. This process was performed to reduce the amount of moisture and paste lost in the drum during batching. It should be noted that an “Over-Mortaring” technique according to ASTM C 192 was also used to compensate for mortar retained by the mixer. The amount of mortar increase was set at 3% for each batch. This amount was designated by the primary investigator, Dr. Seamus Freyne. After the wetting of the drum, the aggregates and half of the water dosage required was added. The mixer was then started and run for five minutes. At the completion of this cycle, the remaining water, cementitious materials, and admixtures were added. After these additions, the mixer was set to finish running for six minutes. Each of the cycle timings began with the addition of the water. These times were noted and then controlled with a stopwatch. For investigation purposes, adjustments of the admixture addition timings and extra cycles were developed in the second level of testing. These were done to acquire the air contents, slumps, and workability needed. Further information on these changes may be found in Chapter 4.

3.4.2 Curing Procedures

Just as with the batching procedure, the curing process throughout the investigation was a modified version of ASTM C 192. This process consisted of placing the specimens in a climate controlled eco-chamber immediately after casting. The chamber was held at a constant 73.4^{o} and a 50% relative humidity. Each batch was cast into four-by-eight cylinders and three-by-three-by-ten inch shrinkage prisms. The four-by-eight cylinder specimens were allowed to sit with their plastic lids on for approximately twenty-four hours from the time of batching. The length change specimens also sat in their molds for this period with the retaining screws loosened to minimize the restraint. At the time the specimens were released, they were immediately placed back into the chamber fully exposed and allowed to air dry for the remainder of the testing.

3.5 Tests Performed

Several tests were performed in this investigation. The following tests are grouped to display which were used for primary and secondary concerns. These include seven performed for the primary criteria and four for the secondary. The secondary were used chiefly for classification purposes. The secondary test of rapid freeze-thaw, splitting tensile, and air void analysis were performed on the samples taken in the field investigation (see Chapter 6). The primary tests include:

1) Compressive Strength (Section 3.5.1)
2) Unrestrained Length Change (Section 3.5.2)
3) Dry-Rodded Unit Weight (Section 3.5.3)
4) Unit Weight (Section 3.5.4)
5) Slump (Section 3.5.5)
6) Air Content (Section 3.5.6)
7) Concrete Temperature (Section 3.5.7)

The secondary includes:

1) Modulus of Elasticity (Section 3.5.8)
2) Rapid Freeze-Thaw (Section 3.5.9)
3) Splitting Tensile (Section 3.5.10)
4) Air Void Analysis (Section 3.5.11)

3.5.1 Compressive Strength

Compressive strength is one of the most common concrete tests performed. One reason for this is its ability to relate to several other tests that are of importance such as tensile strength and modulus of elasticity. Another reason is the strength found is often used as a gauge of the quality of a concrete mix. Additionally, this test is easily performed and it has a high degree of reproducibility.

The resulting test values are dependent on the size and shape of the specimens used in testing. For this investigation, three four-by-eight cylinders were used for each batch testing at 1, 3, 28, and 56 days in agreement with ASTM C 39 (ASTM 1995), "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens". The compressive strength of the specimen was performed on a Forney®, LC-1 concrete testing machine, serial #96054, calibrated in February 2005. The Forney® was programmed to divide the peak load attained during the test by the cross-sectional area of the specimen. A digital read out was then provided of the ultimate load and the ultimate stress. These were then manually recorded. Figure 3.2 displays a set up for the compressive strength test.

Figure 3. 2 – Compressive Strength Test (Kao, 2005)

3.5.2 Unrestrained Length Change

One of the major focuses of this HPC investigation is concrete shrinkage. To monitor the batches for shrinkage, an unrestrained length change test was performed on each. This test allows assessment of the potential volumetric changes (plastic, autogeneous, carbonation, and drying) of which are not caused by applied forces or external temperature change.

The tests were performed along with ASTM C 157, “Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete”. The shrinkage molds used in this test contain a 10 inch gage length. Three length change prisms were casted for each batch. When measuring, the reference bar was used before and after measuring the three prisms. Figure 3.3 displays a shrinkage prism during testing (left) and the reference bar for calibration (right).

Figure 3. 3 – Unrestrained Length Change Test (Kao, 2005)

In the curing process, dowels were used under the specimens to prevent restraining forces from affecting the accuracy of the measurements. Each of these measurements were taken in the actual eco-chamber to assure that the specimens stayed at a constant temperature and humidity which was at a constant 73.4^{o} and 50% respectively. The initial measurement was taken twenty-four hours after casting. This initial reading is of importance since the following measurements are in reference to it. The subsequent measurements were set with a testing regime of 3, 7, 14, 21, 28, and 56 days. To calculate the change, the following equation was used:

$$\Delta L_x = \frac{CRD - CRD_{initial}}{G} \times 100 \qquad \textbf{Equation 3. 1}$$

Where:

ΔL_x = length change of specimen at any age, %

CRD = difference between the comparator reading of the specimen and the reference bar at any age

G = the gage length (10 inches or 250 mm)

3.5.3 Dry-Rodded Unit Weight

The dry-rodded unit weight (DRUW) indicates the density of aggregates in concrete. This test provided information of great use in this investigation because of the large focus on aggregate blends. The DRUW test offered a method to examine the distribution of aggregate particle sizes in the blend. A higher DRUW was sought out to create fewer voids between the aggregates present.

This test was executed in accordance with ASTM C 29 (ASTM 1995), "Standard Test Method for Unit Weight and Voids in Aggregate" using the "rodding procedure". It should be noted that a ¼ ft^3 container was used in this testing. This test is usually done using a $^1/_3$ ft^3 container for the maximum nominal size aggregate present. This change was performed for feasibility reasons and was kept constant for all blends tested.

3.5.4 Unit Weight

The unit weight was calculated for each batch to determine the weight in pounds per cubic foot of the concrete. This test was performed as a quality control measurement of the freshly mixed concrete as well as a comparison to the DRUW. For each batch, the theoretical unit weight was checked against the actual unit weight with the yield given then recorded. The procedure followed to find the unit weight was taken from ASTM C 138 (ASTM 1995), “Standard Test Method for Unit Weight, Yield, and Air Content”.

3.5.5 Slump

The slump test is designed to provide a check on the workability of unhardened concrete. This test allows the concrete to provide a measure of resistance against its own weight. In return, the slump test may be used to judge, with experience of concrete mixing, the consistency of the concrete. Any change in the slump indicates a change in the mixture. This form of quality control is popular and often performed due to its simplicity and low cost. The slump testing in this investigation was performed on all batches with respect to ASTM C 143 (ASTM 1995), “Standard Test Method for Slump of Hydraulic Cement Concrete”. Figure 3.4 displays the equipment used for a slump test.

Figure 3. 4 – Slump Test (Kao, 2005)

3.5.6 Air Content

Being able to know the air content of each batch was vital to this investigation due to the criteria set by ODOT. The voids formed by the air reduce tensile forces in the concrete from the ice crystals that develop during freeze-thaw cycles. This effect will extend the service life and the durability of the concrete.

Entrapped air will always be present in a concrete mix; however, entrained air can be manipulated with air-entraining admixtures. The entrapped air content generally accepted in concrete is approximately 2%, which was verified in this study. This leads to any additional air being developed by entrainment. To ensure an accurate measurement, the total air (entrained and entrapped) content of the fresh concrete was measured during casting.

In this study, the air content was established consistently through the batches with respect to ASTM C 231 (ASTM 1995), “Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method”. This standard lists more than one type of meter that may be used. In this investigation a Type B meter was used consistently. Figure 3.5 displays the air pot used in this investigation.

Figure 3. 5 – Air Content Test (Kao, 2005)

It should be noted that the pressure method only finds the air content of fresh concrete. The hardened concrete may achieve higher or lower air contents. Several factors can play a role in this change such as the consolidation effort, the uniformity and stability of the air bubbles, environmental exposure, as well as the construction methods used. None the less, this test is a valuable indicator of the actual amount of air and is widely used due to its ease and affordability.

3.5.7 Concrete Temperature

The rate of hardening of concrete is influenced by the temperature.   There is some thought that concrete that cures at an early age tends to develop a higher amount of shrinkage due to this phenomenon. For this reason, the concrete temperature was monitored and attempted to be controlled. This was done with experience developed during the batching process. When it was believed that the concrete would be too warm, the aggregates were stored at lower temperatures and ice was added to the batching water to lower the overall concrete temperature. This was necessary to obtain the goals for the mixtures set by ODOT. The temperature of the fresh concrete was measured during casting through ASTM C 1064 (ASTM 1995), “Standard Test Method for Temperature of Freshly Mixed Portland Cement Concrete”.

3.5.8 Modulus of Elasticity

The modulus of elasticity test provides a stress to strain ratio of the concrete. This value when obtained can be used to size structural members, establish the amount of reinforcing needed, and compute stress for observed strains. However, the value found may only be considered within the first 40% of the ultimate concrete strength, 0 to 40% range.

When finding the modulus of elasticity in this investigation, four-by-eight cylindrical specimens were used. These specimens were then fitted with an external, electronic extensiometer. The extensiometer was connected to the same Forney® LC-1 concrete testing machine mention in Section 3.5.1. Figure 3.6 displays a modulus test setup. After the setup was completed, the machine was then loaded in a compression test at a rate of 23,000 to 30,000 pounds per second for each of these tests. The stress and strain was monitored during this process with the Forney® through an internal data acquisition system. This process was performed at the 28 day curing time for each specimen in accordance with ASTM C 469 (ASTM 1995), “Standard Test Method for Static Modulus of Elasticity and Poisson’s Ratio of Concrete in Compression”. When all the data was recorded and calculated the following equation was used:

$$E = \frac{S_2 - S_1}{\varepsilon_2 - 0.000050} \qquad \textbf{Equation 3. 2}$$

Where:

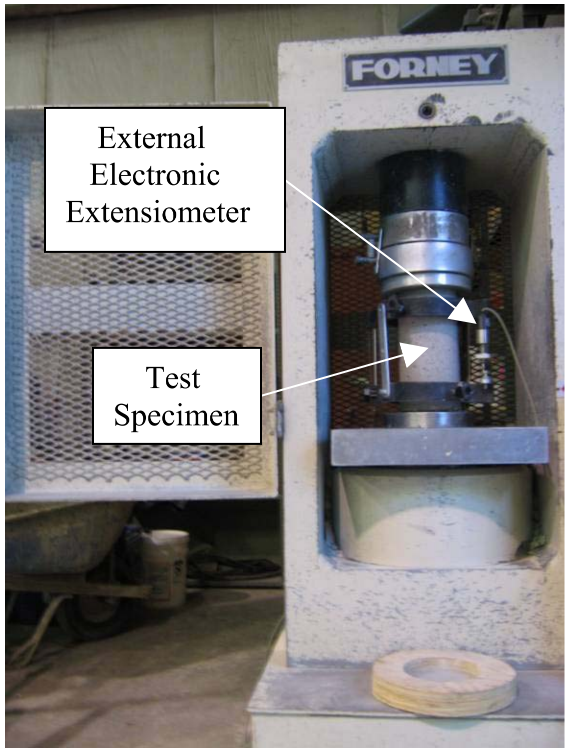
E = chord modulus of elasticity, psi

S_2 = stress corresponding to 40% of ultimate load

S_1 = stress corresponding to a longitudinal strain, ε_1, of 50 millionths, psi,

ε_2 = longitudinal strain produced by stress S_2

Figure 3. 6 – Modulus of Elasticity Test (Kao, 2005)



3.5.9 Rapid Freeze-Thaw

The results achieved from this test are valuable due to Oklahoma's history of freeze-thaw cycles ranking as one of the highest in the United States. The freeze-thaw test allows the resistance of the concrete to rapidly repeating freezing and thawing cycles to be viewed. If the specimens are deemed to be relatively unaffected to the processes, then the specimens can be considered to have not been critically saturated, or to have been made with proper aggregates, air-void ratios, and allowed to develop properly. The actual testing performed in this investigation was done following ASTM C 666 (ASTM 1995), "Standard Test for Resistance of Concrete to Rapid Freezing and Thawing". It should be noted that "Procedure A - Rapid Freezing and Thawing in Water" was the method used in this research. In addition, the type of fundamental transverse frequency reader used was a forced resonance apparatus. These readings were performed according to ASTM C 215 (ASTM 1995), “Standard Test Method for Fundamental Transverse, Longitudinal, and Torsional Frequencies of Concrete Specimens”. After the data is found, the following equations are used to find the relative dynamic modulus of elasticity and durability factor:

$$P_c = \left(n_1^2 / n^2\right) \times 100 \qquad \textbf{Equation 3. 3}$$

Where:

P_c = relative dynamic modulus of elasticity, after c cycles of freezing and thawing, %

n = fundamental transverse frequency at 0 cycles of freezing and thawing

n_1 = fundamental transverse frequency after c cycles of freezing and thawing

$$DF = PN / M$$ **Equation 3. 4**

Where:

DF = durability factor of the test specimen

P = relative dynamic modulus of elasticity at N cycles, %

N = number of cycles at which P reaches the specified minimum value for discontinuing the test or the specified number of cycles at which the exposure is to be terminated, whichever is less

M = specified number of cycles at which the exposure is to be terminated

Figure 3.7 and 3.8 display the freeze-thaw chamber set up and transverse frequency reader, respectively.

Figure 3. 7 – Freeze-Thaw Chamber Set Up

Figure 3. 8 – Transvers Frequency Reader Set Up

3.5.10 Tensile Strength

The determination of tensile strength was carried out in agreement with ASTM C 496, “Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens”. This is a common test performed due to its ease of application and ability to correlate to other concrete properties such as compressive strength and the modulus of elasticity.

The actual test was performed on the same Forney®, LC-1 concrete testing machine used in the compressive strength and modulus of elasticity tests using four-by-eight cylindrical specimens. A setup of a splitting tensile test is provided in Figure 3.9. At the end of each test, the Forney® presented the resulting peak load applied at the time of failure. This information was then recorded and used in the following equation to provide the tensile strength of the specimen:

$$T = \frac{2 \times P}{\pi \times l \times d} \qquad \textbf{Equation 3. 5}$$

Where:

T = splitting tensile strength, psi (ksi)

P = peak applied load, lbf (kN)

l = length, in (m)

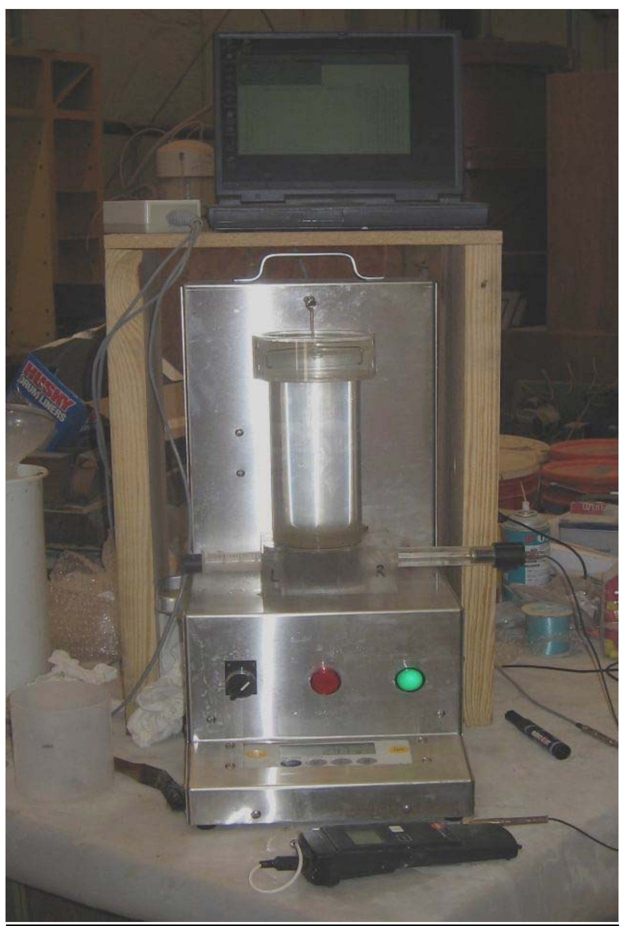
d = diameter, in (m)

Figure 3. 9 – Splitting Tensile Strength Test (Kao, 2005)

3.5.11 Air Void Analysis

The Air Void Analysis (AVA) testing is an additional air content study which is concerned with size distribution of the air bubbles within the concrete. This test was performed by taking a mortar sample from the fresh concrete with a vibrating cage and syringe. This sample was then injected into a testing apparatus containing a liquid with a known viscosity. As the sample was injected, the air bubbles began to rise through the liquid to a buoyancy recorder. This is important since the rate of buoyancy found is a function of the size. The recorded data was then processed through data acquisition system that provides information on the total air content, spacing factor, and specific surface of the concrete. In this investigation, the AVA sampling was conducted by the researchers during the field investigation. However, the actual testing and analysis was performed by a contracted researcher. Figure 3.10 displays an image of the AVA testing apparatus used in this investigation.

Figure 3. 10 – AVA Testing Apparatus



3.6 Chapter Summary

This chapter contains information for the investigation on the variables, mix design development, batching and curing procedures, and the tests performed. The process of the mix design development is explained through variables including cementitious materials, aggregates, and admixtures. Also included is a sequence of investigation to further explain the matrices and progressive methods used in the batching. A variety of different test are additionally explained in detail with the corresponding applicable standard. These tests include those for primary consideration and those carried out for secondary or classification purposes.

CHAPTER 4 – Test Results

4.1 Introduction

This chapter provides the test results from the investigation. The results are displayed in the same sequence that the testing was performed in the research. By displaying the results in this manner, the progressive testing format used is more easily followed.

4.2 Primary Investigation

4.2.1 Preliminary Batches

The purpose of the preliminary batches was to create the mixing, curing, and testing regimes to be used as well as to serve as typical mixes that may be batched in current construction practices. This batching group consists of Batches 1 and 2 which were performed prior to obtaining the local aggregates of focus for the investigation. The aggregates used in these batches were Richardson Spur #2 limestone and Dover quartz sand. The actual designs for the preliminary batches included different amounts of total cementitious materials; however, an equal proportioning of the same cement and fly ash were used, 80% and 20%, respectively. This lead to 640.6 lb/yd^3 (380 kg/m^3) of total cementitious materials for Batch 1 while Batch 2 contained 674.4 lb/yd^3 (400 kg/m^3). For each of the batches, a w/cm ratio of 0.38 was used. In addition, both batches consisted of a mid-range water-reducer dosage rate of 10.3 fl oz/cwt (6.0

mL/kg) of cementitious materials and an air-entrainer dosage rate of 3.4 fl oz/cwt (2.0 mL/kg). Table 4.1 presents the batch proportions and design as well as the fresh and hardened properties for these two batches.

Table 4. 1 – Fresh and Hardened Properties of Preliminary Batches

				Batch # =	
				1	**2**
MIX PROPORTIONS (SSD AGGREGATES)	**Cement**		**lb/yd^3 (kg/m^3)**	512.5 (304.0)	539.5 (320.0)
	Fly Ash		**lb/yd^3 (kg/m^3)**	128.1 (76.0)	134.9 (80.0)
	Richardson Spur Coarse Aggregate (#2)		**lb/yd^3 (kg/m^3)**	1,704.4 (1,010.9)	1,668.1(989.4)
	Dover Sand		**lb/yd^3 (kg/m^3)**	1,285.7 (762.6)	1,258.3 (746.3)
	Mixing Water		**lb/yd^3 (kg/m^3)**	240.4 (142.6)	253.1 (150.1)
	Air-Entrainer (MB AE™90)		**fl.oz/yd^3 (mL/m^3)**	19.6 (760.0)	20.7 (800.0)
	Mid-Range Water-Reducer (Polyheed® 1020)		**fl.oz/yd^3 (mL/m^3)**	58.9 (2,280.0)	62.0 (2,400)
DESIGN INFORMATION	**Specific Gravity (Coarse Aggregate #2)**			2.67	2.67
	Specific Gravity (Sand)			2.63	2.63
	w/cm			0.380	0.380
	w/c			0.475	0.475
	Supplemental CM / Total CM		**%**	20.0	20.0
	Paste Content (by Vol)		**%**	27.14	28.57
	Aggregate Content (by Vol)		**%**	66.86	65.43
	Designed Air Content (by Vol)		**%**	6.00	6.00
	Total (by Vol)		**%**	100.00	100.00
BATCH DATA	**Calculated Unit Weight**		**lb/ft^3 (kg/m^3)**	3,877 (2,300)	3,860 (2,290))
	Measured Unit Weight		**lb/ft^3 (kg/m^3)**	3,772 (2,237)	3,487 (2,068)
	Yield			1.03	1.11
	Dry Rodded Unit Weight		**lb/ft^3 (kg/m^3)**	127 (2,034)	127 (2,034)
	Air Temperature		**°F (°C)**	81 (27.2)	81 (27.2)
	Relative Humidity		**%**	55	55
	Concrete Temperature		**°F (°C)**	81 (27.2)	81 (27.2)
	Slump		**inches (mm)**	4.6 (127)	5.75 (127)
	Air Content (by Vol)		**%**	9.0	14.0
	Compressive Strength	**24 hours**	**psi (Mpa)**	1608 (12)	561 (4)
		3 days	**psi (Mpa)**	3048 (21)	1311 (9)
		28 days	**psi (Mpa)**	3416 (24)	1290 (9)
		56 days	**psi (Mpa)**	3390 (23)	1366 (9)
	Shrinkage	**28 days**	**in^{-6}/in (m^{-6}/m)**	470 (470)	410 (410)
	Modulus of Elasticity	**28 days**	**psi (Mpa)**	2.91x10^6 (20,082)	1.77x10^6 (12,223)

4.2.2 Matrix 1 (Air-Entrainer)

The purpose of Matrix 1 was to see the affects of the air-entraining admixture, MB AE™ 90, a product of Degussa Admixtures, Incorporated. To do this, two batches were performed. The first, Batch 3, was developed using an air-entrainer dosage rate of 3.4 fl oz/cwt (2.0 mL/kg) of cementitious materials, which lies within the manufacturer's recommended range; the second, Batch 4, was performed omitting the entrainer. For both batches in this matrix, a cementitious materials content of 640.6 lb/yd^3 (380 kg/m^3) was used, which was divided into 80% cement and 20% fly ash. In addition, both batches consisted of a w/cm ratio of 0.38 and a dosage rate of 10.3 fl oz/cwt (6.0 mL/kg) for the mid-range water reducer.

For each mix design, the air contents expected or desired were considered. Batch 3 was designed for 8% of the volume to consist of air, which was due to the goals set by ODOT for the investigation. The actual air content recorded at batching was 10.5%. This variation in design and actual air contents is just an inclination of the difficulties of achieving desired air contents due to the air-entrainer's multiple variables. In contrast to Batch 3, Batch 4 was designed with an expected 2% of the volume to consist of air. This volume was used due to experience of concrete without air-entrainer having an air content around 2%. The actual air content of 1.9% found at the time of batching supports this assumption. The fresh and hardened properties as well as the batch proportions and design for Matrix 1 are presents in Table 4.2.

Table 4. 2 – Fresh and Hardened Properties of Matrix 1 (Air Content) and 2 (Cementitious Materials Content)

			Matrix 1 - Air Content		Matrix 2 - Cementitious Materials Content			
			Batch # =		Batch # =			
			3	4	3	5	6	7
MIX PROPORTIONS (SSD AGGREGATES)	Cement	lb/yd^3 (kg/m^3)	512.5 (304.0)	512.5 (304.0)	**512.5 (304.0)**	**485.6 (288.0)**	**458.6 (272.0)**	**431.6 (256.0)**
	Fly Ash	lb/yd^3 (kg/m^3)	128.1 (76.0)	128.1 (76.0)	**128.1 (76.0)**	**121.4 (72.0)**	**114.6 (68.0)**	**107.9 (64.0)**
	Cooperton Coarse Aggregate (#57)	lb/yd^3 (kg/m^3)	1,074.0 (637.0)	1,174.0 (696.3)	1,074.0 (637.0)	1,097.6 (651.0)	1,121.4 (665.1)	1,145.0 (679.1)
	Cooperton Intermediate Aggregate (3/8" Chip)	lb/yd^3 (kg/m^3)	696.7 (413.2)	761.4 (451.6)	696.7 (413.2)	712.0 (422.3)	727.3 (431.4)	742.7 (440.5)
	Comargo Sand	lb/yd^3 (kg/m^3)	1132.0 (671.4)	1237.4 (733.9)	1132.0 (671.4)	1156.9 (686.2)	1,181.9 (701.0)	1,206.8 (715.8)
	Mixing Water	lb/yd^3 (kg/m^3)	240.4 (142.6)	241.1 (143.0)	240.4 (142.6)	227.8 (135.1)	215.1 (127.6)	202.5 (120.1)
	Air-Entrainer (MB AE™90)	fl.oz/yd^3 (mL/m^3)	**19.6 (760.0)**	---	19.6 (760.0)	18.6 (720.0)	17.6 (680.0)	16.5 (640.0)
	Mid-Range Water-Reducer (Polyheed® 1020)	fl.oz/yd^3 (mL/m^3)	58.9 (2,280.0)	58.9 (2,280.0)	58.9 (2,280.0)	55.8 (2,160.0)	52.7 (204.0)	49.6 (192.0)
DESIGN INFORMATION	Specific Gravity (Coarse and Inter. Aggregates)		2.67	2.67	2.67	2.67	2.67	2.67
	Specific Gravity (Sand)		2.63	2.63	2.63	2.63	2.63	2.63
	w/cm		0.380	0.380	0.380	0.380	0.380	0.380
	w/c		0.475	0.475	0.475	0.475	0.475	0.475
	Supplemental Cem. Mat. / Total Cem. Mat.	%	20.0	20.0	20.0	20.0	20.0	20.0
	Paste Content (by Vol.)	%	27.14	27.10	27.14	25.71	24.28	22.85
	Aggregate Content (by Vol.)	%	64.86	70.90	64.86	66.29	67.72	69.15
	Designed Air Content (by Vol.)	%	8.00	2.00	8.00	8.00	8.00	8.00
	Total (by Vol.)	%	100.00	100.00	100.00	100.00	100.00	100.00
BATCH DATA	Calculated Unit Weight	lb/yd^3 (kg/m^3)	3,790 (2,248)	4,059 (2,408)	3,790 (2,248)	3,807 (2,258)	3,824 (2,268)	3,842 (2,279)
	Measured Unit Weight	lb/yd^3 (kg/m^3)	3,681 (2,183)	4,138 (2,454)	3,681 (2,183)	3,566 (2,115)	3,911 (2,319)	3,942 (2,338)
	Yield		1.03	0.98	1.03	1.07	0.98	0.97
	Dry Rodded Unit Weight	lb/yd^3 (kg/m^3)	3,403 (2,018)	3,403 (2,018)	3,403 (2,018)	3,403 (2,018)	3,403 (2,018)	3,403 (2,018)
	Air Temperature	°F (°C)	70 (27.2)	75 (23.9)	70 (27.2)	91 (32.8)	91 (32.8)	90 (32.2)
	Relative Humidity	%	74	68	74	58	57	59
	Concrete Temperature	°F (°C)	N/R	78 (25.6)	N/R	82 (27.8)	84 (28.9)	84 (28.9)
	Slump	inches (mm)	4.25 (108)	1.75 (44)	4.25 (108)	4.00 (102)	1.75 (44)	1.25 (32)
	Air Content (by Vol.)	%	10.5	1.9	10.5	13.5	7.2	6.4
	Hardened Properties:							
	Compressive Strength 24 hours	psi (Mpa)	1444 (10)	2153 (15)	1444 (10)	678 (5)	1509 (10)	1651 (11)
	3 days	psi (Mpa)	2514 (17)	4901 (34)	2514 (17)	1549 (11)	3221 (22)	3605 (25)
	28 days	psi (Mpa)	2464 (17)	5618 (39)	2464 (17)	1292 (9)	3277 (23)	4042 (28)
	56 days	psi (Mpa)	2463 (17)	5818 (40)	2463 (17)	1425 (10)	3309 (23)	3775 (26)
	Shrinkage 28 days	in^{-6}/in (m^{-6}/m)	337 (337)	226 (226)	337 (337)	443 (443)	266 (266)	260 (260)
	Modulus of Elasticity 28 days	psi (Mpa)	2.45x10^6 (16,899)	4.43x10^6 (30,520)	2.45x10^6 (16,899)	1.69x10^6 (11,641)	3.57x10^6 (24,640)	3.65x10^6 (25,154)

4.2.3 Matrix 2 (Cementitious Materials Content)

The purpose of the study in Matrix 2 was to determine the appropriate amount of total cementitious materials for the investigation. This was done by using a cementitious materials blend of 80% cement and 20% fly ash for each batch just as in the previous matrix. For this study, the w/cm ratio was held at a constant 0.38 and the mid-range water reducer was set at a rate of 10.3 fl oz/cwt (6.0 mL/kg). In addition, the air-entrainer dosage rate developed in Matrix 1 was adopted into Matrix 2 for each batch, 3.4 fl oz/cwt (2.0 mL/kg). Table 4.2 on the previous page contains the mix proportions and design information as well as fresh and hardened concrete properties for Matrix 2.

In concrete practice, it is common knowledge that the cementitious materials, or more accurately the Portland cement, develop most of the material cost. In addition, the cementitious materials are directly linked with the volumetric change of the concrete. With this in mind, the investigators tried to lower the total amount in each batch of this study. This was performed through four batches developed for Matrix 2. The first consists of Batch 3 from the Matrix 1 study with 640.6 lb/yd^3 (380 kg/m^3) of cementitious materials. From this cementitious materials content, each of the succeeding batches was lowered. These include Batch 5 which consists of 607.0 lb/yd^3 (360 kg/m^3), Batch 6 with 573.2 lb/yd^3 (340 kg/m^3), and Batch 7 with 539.5 lb/yd^3 (320 kg/m^3).

4.2.4 Matrix 3 (Aggregate Blend)

To produce a quality concrete, the aggregate blend of the concrete should be analyzed rather than the aggregate stockpiles that are available. This is one of the primary focuses of this research. Matrix 3 consists of a study on the optimum aggregate gradation for the mixtures in this investigation.

The gradation found in this study will, in theory, create the concrete with the largest aggregate density or more simply have the least amount of voids between the aggregate particles. With this optimized gradation and the appropriate w/cm ratio, the total amount of cement needed should be minimized. In turn, the need for less cementitious materials and mixing water creates a lower cost per volume of the concrete and segregation issues in the mobility of the concrete should be improved. Another benefit from using less water and cementitious materials is found in the decrease in volumetric changes of the concrete. This optimized gradation helps to develop a concrete more similar to solid stone due to the increase in aggregate used which produces smaller volume changes. With a more economical product in addition to a longer service life, it can easily be seen why this study is beneficial to concrete producers as well as the owners of the constructed structures.

The Matrix 3 study was performed through the examination of twelve batches. Each of which consisted of the following aggregates in different amounts and combinations: #57, #2, and 3/8” chip Cooperton limestone as well as Camargo sand. The first batch of the twelve consists of Batch 6 from Matrix 2. The designs for each of the following batches were identical except for the aggregate blends which were chosen using the Shilstone method. Table 4.3 contains a breakdown of the aggregate blends used for each batch. All of the batches contained a w/cm ratio of 0.38, a mid-range water reducer dosage rate of 10.3 fl oz/cwt (6.0 mL/kg), an air-entrainer dosage rate of 3.4 fl oz/cwt (2.0 mL/kg), and a total cementitious materials content of 573.2 lb/yd^3 (340 kg/m^3) which was divided into 80% cement and 20% fly ash. The fresh and hardened properties of Matrix 3 as well as the batch proportions are presented in Table 4.4 and 4.5.

Table 4. 3 – Aggregate Blends for Matrix 3

	Cooperton			Comargo		
	Coarse		Intermediate	Fine	Blend	DRUW
Batch #	#57	#2	3/8" chip	sand	TOTAL	
6	37%	---	24%	39%	100%	126.0
8	35%	26%	---	39%	100%	129.6
9	25%	---	37%	38%	100%	123.9
10	43%	---	27%	30%	100%	122.9
11	20%	41%	---	39%	100%	129.9
12	15%	40%	---	45%	100%	124.5
13	35%	---	19%	46%	100%	126.8
14	26%	---	30%	44%	100%	122.9
15	32%	---	27%	41%	100%	123.2
20	15%	37%	---	48%	100%	124.8
21	41%	---	11%	48%	100%	128.8
25	Blended by sieve size.				100%	123.9

Table 4. 4 – Fresh and Hardened Properties of Matrix 3 (Aggregate Blend) (Table 1 of 2)

				Matrix 3 - Aggregate Blend					
				Batch # =					
				6	8	9	10	11	12
MIX PROPORTIONS (SSD AGGREGATES)	Cement		lb/yd^3 (kg/m^3)	458.6 (272.0)	458.6 (272.0)	458.6 (272.0)	458.6 (272.0)	458.6 (272.0)	458.6 (272.0)
	Fly Ash		lb/yd^3 (kg/m^3)	114.6 (68.0)	114.6 (68.0)	114.6 (68.0)	114.6 (68.0)	114.6 (68.0)	114.6 (68.0)
	Cooperton Coarse Aggregate (#57)		lb/yd^3 (kg/m^3)	1,121.4 (665.1)	1,060.7 (629.1)	757.7 (449.4)	1,304.8 (773.9)	606.1 (359.5)	454.2 (269.4)
	Cooperton Coarse Aggregate (#2)		lb/yd^3 (kg/m^3)	---	787.9 (467.3)	---	---	1,242.5 (737.0)	1,211.1 (718.3)
	Cooperton Intermediate Aggregate (3/8" Chip)		lb/yd^3 (kg/m^3)	727.3 (431.4)	---	1,121.5 (665.2)	819.4 (486.0)	---	---
	Comargo Sand		lb/yd^3 (kg/m^3)	1,181.9 (701.0)	1,181.9 (701.0)	1,151.8 (683.1)	910.4 (540.0)	1,181.9 (701.0)	1,362.5 (808.1)
	Mixing Water		lb/yd^3 (kg/m^3)	215.1 (127.6)	215.1 (127.6)	215.1 (127.6)	215.1 (127.6)	215.1 (127.6)	215.1 (127.6)
	Air-Entrainer (MB AE™90)		fl.oz/yd^3 (mL/m^3)	17.6 (680.0)	17.6 (680.0)	17.6 (680.0)	17.6 (680.0)	17.6 (680.0)	17.6 (680.0)
	Mid-Range Water-Reducer (Polyheed® 1020)		fl.oz/yd^3 (mL/m^3)	52.7 (2,040.0)	52.7 (2,040.0)	52.7 (2,040.0)	52.7 (2,040.0)	52.7 (2,040.0)	52.7 (2,040.0)
DESIGN INFORMATION	Specific Gravity (Coarse and Inter. Aggregates)			2.67	2.67	2.67	2.67	2.67	2.67
	Specific Gravity (Sand)			2.63	2.63	2.63	2.63	2.63	2.63
	w/cm			0.380	0.380	0.380	0.380	0.380	0.380
	w/c			0.475	0.475	0.475	0.475	0.475	0.475
	Supplemental Cem. Mat. / Total Cem. Mat.		%	20.0	20.0	20.0	20.0	20.0	20.0
	Paste Content (by Vol.)		%	24.28	24.28	24.28	24.28	24.28	24.28
	Aggregate Content (by Vol.)		%	67.72	67.72	67.72	67.72	67.72	67.72
	Designed Air Content (by Vol.)		%	8.00	8.00	8.00	8.00	8.00	8.00
	Total (by Vol.)		%	100.00	100.00	100.00	100.00	100.00	100.00
BATCH DATA	Calculated Unit Weight		lb/yd^3 (kg/m^3)	3,824 (2,268)	3,824 (2,268)	3,825 (2,269)	3,828 (2,271)	3,824 (2,268)	3,822 (2,267)
	Measured Unit Weight		lb/yd^3 (kg/m^3)	3,911 (2,319)	3,903 (2,315)	3,661 (2,171)	4,049 (2,402)	3,929 (2,330)	3,905 (2,316)
	Yield			0.98	0.98	1.04	0.95	0.97	0.98
	Dry Rodded Unit Weight		lb/yd^3 (kg/m^3)	3,403 (2,018)	3,498 (2,075)	3,346 (1,985)	3,318 (1,968)	3,507 (2,080)	3,362 (1,995)
	Air Temperature		^{o}F (^{o}C)	91 (32.8)	87 (30.6)	88 (31.1)	81 (27.2)	88 (31.1)	87 (30.6)
	Relative Humidity		%	57	60	60	55	42	39
	Concrete Temperature		^{o}F (^{o}C)	84 (28.9)	81 (27.2)	80 (26.7)	77 (25.0)	84 (28.9)	80 (26.7)
	Slump		inches (mm)	1.75 (44)	2 (51)	2.5 (64)	4 (102)	0.75 (19)	1 (25)
	Air Content (by Vol.)		%	7.2	7.2	11.0	4.5	6.4	7.0
	Compressive Strength	24 hours	psi (Mpa)	1509 (10)	1219 (8)	884 (6)	2607 (18)	1328 (9)	1571 (11)
		3 days	psi (Mpa)	3221 (22)	3349 (23)	2146 (15)	4194 (29)	2827 (19)	3078 (21)
		28 days	psi (Mpa)	3277 (23)	4002 (28)	2359 (16)	5382 (37)	3412 (24)	3770 (26)
		56 days	psi (Mpa)	3309 (23)	3564 (25)	2356 (16)	4613 (32)	3378 (23)	3554 (25)
	Shrinkage	28 days	in^{-6}/in (m^{-6}/m)	266 (266)	283 (283)	397 (397)	213 (213)	293 (293)	317 (317)
	Modulus of Elasticity	28 days	psi (Mpa)	3.57×10^6 (24,640)	3.57×10^6 (24,630)	2.47×10^6 (17,029)	3.97×10^6 (27,352)	3.10×10^6 (21,390)	3.23×10^6 (22,306)

Table 4. 5 – Fresh and Hardened Properties of Matrix 3 (Aggregate Blend) (Table 2 of 2)

			Matrix 3 - Aggregate Blend (Continued...)					
			Batch # =					
			13	14	15	20	21	25
MIX PROPORTIONS (SSD AGGREGATES)	Cement	lb/yd^3 (kg/m^3)	458.6 (272.0)	458.6 (272.0)	458.6 (272.0)	458.6 (272.0)	458.6 (272.0)	458.6 (272.0)
	Fly Ash	lb/yd^3 (kg/m^3)	114.6 (68.0)	114.6 (68.0)	114.6 (68.0)	114.6 (68.0)	114.6 (68.0)	114.6 (68.0)
	Cooperton Coarse Aggregate (#57)	lb/yd^3 (kg/m^3)	1,059.6 (628.4)	787.3 (467.0)	969.5 (575.0)	454.0 (269.3)	1,240.9 (736.0)	3,048.5 (1,808.1) Aggregates seperated by sieve size
	Cooperton Coarse Aggregate (#2)	lb/yd^3 (kg/m^3)	---	---	---	1,119.8 (664.2)	---	
	Cooperton Intermediate Aggregate (3/8" Chip)	lb/yd^3 (kg/m^3)	575.2 (341.2)	908.5 (538.8)	818.0 (485.2)	---	332.8 (197.4)	
	Comargo Sand	lb/yd^3 (kg/m^3)	1,392.6 (826.0)	1,332.4 (790.3)	1,242.1 (736.7)	1,452.5 (861.5)	1,452.7 (861.6)	
	Mixing Water	lb/yd^3 (kg/m^3)	215.1 (127.6)	215.1 (127.6)	215.1 (127.6)	215.1 (127.6)	215.1 (127.6)	215.1 (127.6)
	Air-Entrainer (MB AE™90)	fl.oz/yd^3 (mL/m^3)	17.6 (680.0)	17.6 (680.0)	17.6 (680.0)	17.6 (680.0)	17.6 (680.0)	17.6 (680.0)
	Mid-Range Water-Reducer (Polyheed® 1020)	fl.oz/yd^3 (mL/m^3)	52.7 (2,040.0)	52.7 (2,040.0)	52.7 (2,040.0)	52.7 (2,040.0)	52.7 (2,040.0)	52.7 (2,040.0)
DESIGN INFORMATION	Specific Gravity (Coarse and Inter. Aggregates)		2.67	2.67	2.67	2.67	2.67	2.67
	Specific Gravity (Sand)		2.63	2.63	2.63	2.63	2.63	2.67
	w/cm		0.380	0.380	0.380	0.380	0.380	0.380
	w/c		0.475	0.475	0.475	0.475	0.475	0.475
	Supplemental Cem. Mat. / Total Cem. Mat.	%	20.0	20.0	20.0	20.0	20.0	20.0
	Paste Content (by Vol.)	%	24.28	24.28	24.28	24.28	24.28	24.28
	Aggregate Content (by Vol.)	%	67.72	67.72	67.72	67.72	67.72	67.72
	Designed Air Content (by Vol.)	%	8.00	8.00	8.00	8.00	8.00	8.00
	Total (by Vol.)	%	100.00	100.00	100.00	100.00	100.00	100.00
BATCH DATA	Calculated Unit Weight	lb/yd^3 (kg/m^3)	3,821 (2,266)	3,822 (2,267)	3,823 (2,628)	3,820 (2,266)	3,820 (2,266)	3,842 (2,279)
	Measured Unit Weight	lb/yd^3 (kg/m^3)	3,987 (2,365)	3,931 (2,332)	3,989 (2,366)	3,887 (2,306)	3,886 (2,305)	3,975 (2,358)
	Yield		0.96	0.97	0.96	0.98	0.99	0.97
	Dry Rodded Unit Weight	lb/yd^3 (kg/m^3)	3,423 (2,030)	3,822 (1,969))	3,327 (1,974)	3,369 (1,998)	3,477 (2,062)	3,346 (1,985)
	Air Temperature	^{o}F (^{o}C)	91 (32.8)	91 (32.8)	92 (33.3)	91 (32.5)	90 (31.9)	79 (26.1)
	Relative Humidity	%	39	39	41	47	47	46
	Concrete Temperature	^{o}F (^{o}C)	82 (27.8)	86 (30.0)	88 (31.1)	87 (30.3)	85 (29.4)	80 (26.7)
	Slump	inches (mm)	0.5 (13)	1.5 (38)	1.13 (29)	1.13 (29)	0.75 (19)	2 (51)
	Air Content (by Vol.)	%	4.7	5.8	5.1	6.0	8.0	5.3
	Compressive Strength 24 hours	psi (Mpa)	1862 (13)	1773 (12)	2291 (16)	2082 (14)	2011 (14)	1990 (14)
	3 days	psi (Mpa)	3357 (23)	3594 (25)	4220 (29)	3616 (25)	3431 (24)	3636 (25)
	28 days	psi (Mpa)	4404 (30)	4149 (29)	5022 (35)	4314 (30)	4006 (28)	4108 (28)
	56 days	psi (Mpa)	4425 (31)	4025 (28)	4839 (33)	3910 (27)	3804 (26)	4070 (28)
	Shrinkage 28 days	in^{-6}/in (m^{-6}/m)	343 (343)	347 (347)	315 (315)	305 (305)	318 (318)	313 (313)
	Modulus of Elasticity 28 days	psi (Mpa)	3.76x10^6 (25,920)	3.24x10^6 (22,343)	3.81x10^6 (26,245)	3.81x10^6 (26,245)	3.34x10^6 (23,054)	3.40x10^6 (23,417)

4.2.4.1 Aggregate Stockpile Gradations

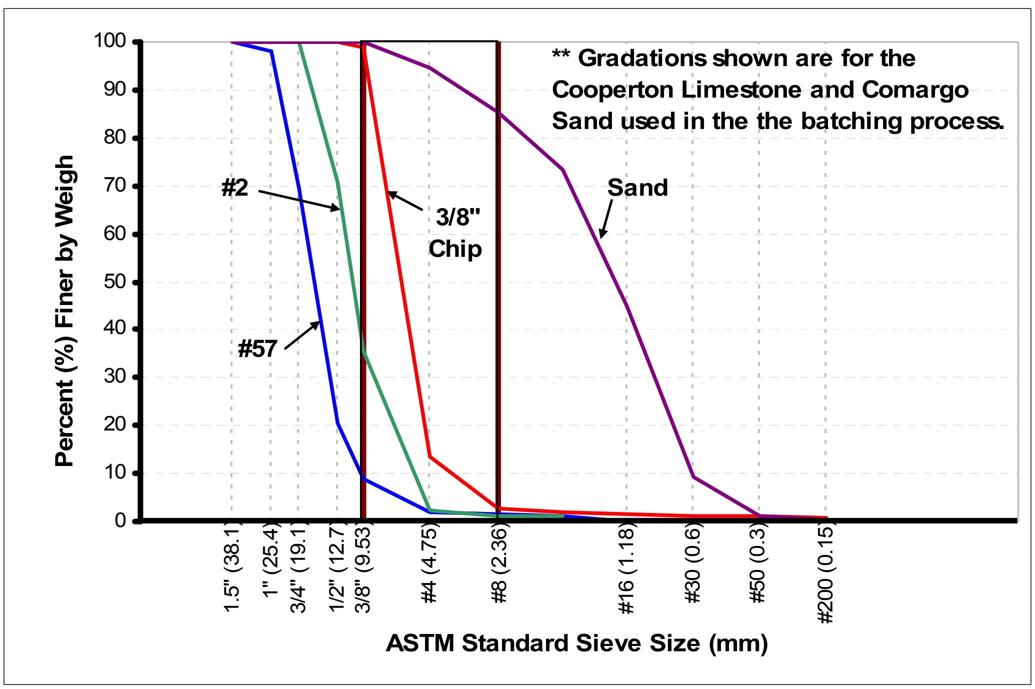
The aggregates to be used in this investigation were sieved by the investigators according to ASTM standards in order to generate the most accurate gradation representation of the materials as possible. The need for this extra sieving was deemed to be crucial since the Shilstone method of blending aggregates used considers the particle size distribution and not the stockpile of the concrete aggregates. The gradation results acquired from the sieving and used in this study are presented in Table 4.6. This data is presented in the form of the percent passing each sieve due to the criteria of blending the aggregates in this study was based on this form of gradation.

Table 4. 6 -- Percent Passing for Each Aggregate Used in the Investigation

	Richards Spur	Dover	Cooperton			Camargo
	#2	Sand	#57	#2	3/8" Chip	Sand
Sieve	%	%	%	%	%	%
38.1 mm (1.5 in)	100.0	100.0	100.0	100.0	100.0	100.0
25.4 mm (1 in)	100.0	100.0	98.0	100.0	100.0	100.0
19.1 mm (3/4 in)	95.2	100.0	69.6	99.9	100.0	100.0
12.7 mm (1/2 in)	51.6	100.0	20.4	70.5	100.0	100.0
9.53 mm (3/8 in)	31.1	100.0	8.9	35.6	98.9	100.0
4.75 mm (#4)	4.4	99.0	1.8	2.4	13.7	94.8
2.36 mm (#8)	0.9	93.9	1.4	1.3	2.8	85.4
1.18 mm (#16)	0.7	80.3	1.2	1.2	1.8	73.4
0.600 mm (#30)	---	51.9	---	---	1.5	44.9
0.300 mm (#50)	---	19.1	---	---	1.3	9.4
0.150 mm (#100)	---	2.7	---	---	1.0	1.0
0.075 mm (#200)	---	0.4	---	---	0.9	0.3

As mentioned, the aggregate in this investigation are considered by the distribution of particle sizes. These aggregates were broken down into categories defined as coarse, intermediate, and fine aggregates. Figure 4.1 displays the aggregates used in the investigation that were presented in the Matrix 3 section of Table 4.6. The regions on the graph shown represent the coarse (far left), intermediate (shaded area), and the fine (far right). It can easily be seen that the #57 and #2 aggregates are classified as coarse, the 3/8" chip as intermediate, and the sand as fine due to the majority of there particle sizes being distributed in the respected regions.

Figure 4. 1 – Percent Passing Gradation of Each Aggregate Used in the Investigation



4.2.4.2 Shilstone Coarseness Factor Chart

The Shilstone method was used in deciding the aggregate blends in this investigation. The aggregate blends are presented in Table 4.7, which include the preliminary batches as well. This method, which is explained in more detail in Chapter 2, simply consists of analyzing the grade of particle sizes in each aggregate source as stated in Section 4.2.4.1. The gradations that were found in this study, see Table 4.6, were then proportioned in different combinations of each aggregate. Each aggregate blend consisted of the sand and #57 coarse aggregate with a combination of the #2 or 3/8" chip aggregates. As can be seen in Figure 4.1, each batch had to contain both the #57 and sand in order to develop enough of the large particles and finer particles required.

The blends were chosen by plotting the Shilstone Coarseness and Workability Factors. The Coarseness Factor is found as the amount greater than the 3/8 inch sieve over the amount greater than the #8 sieve and the workability factor is found as the amount passing the #8 sieve. These values were then plotted on the Shilstone target zone graph which was recreated in a spreadsheet by the primary investigator. The Coarseness and Workability Factors for each blend are presented in Table 4.8 as well as a plot of the blends is presented in Figure 4.2. The blends were chosen to characterize the target zone and to see the affects on the mixture from the different blends. It should be noted that the additional Workability Factor increase for extra cement mentioned in the Chapter 2 explanation of the Shilstone method was not applied in this research.

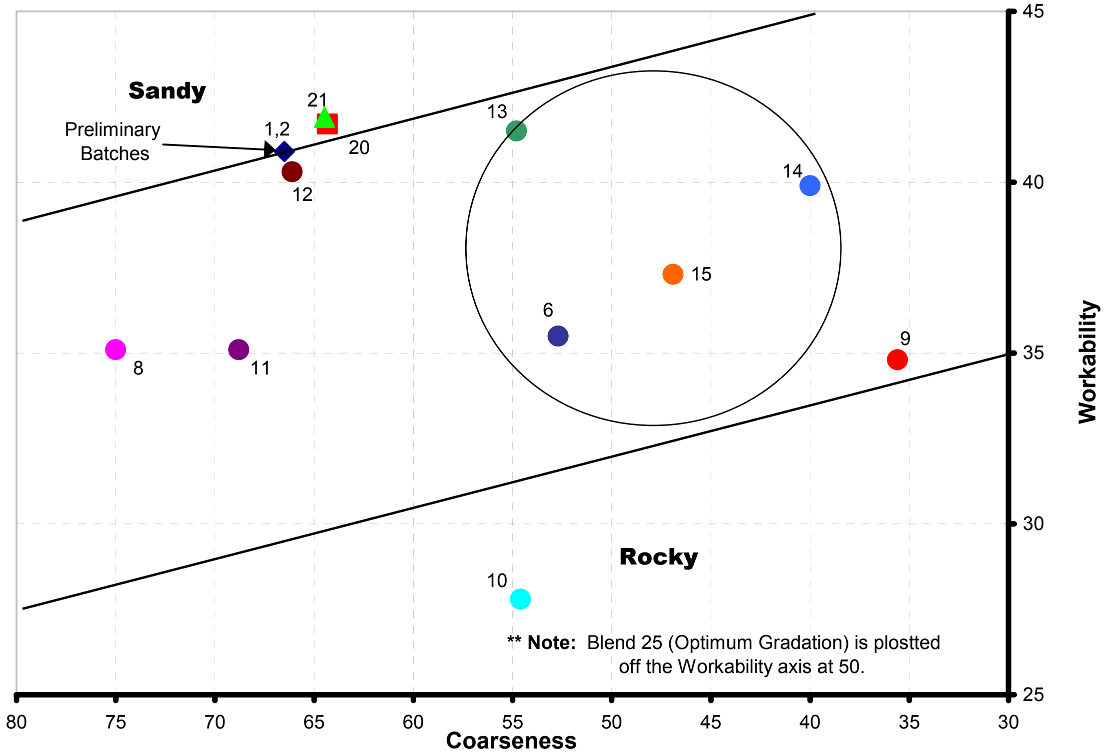
Table 4. 7 – Aggregate Blends

Batch #		Preliminary Batches			
		Richardson Spur			Dover
		Coarse		Intermediate	Fine
		#57		N/A	sand
	1,2	57%		---	43%
		Matrix 3 -- Aggregate Blends			
		Cooperton			Comargo
		Coarse		Intermediate	Fine
		#57	#2	3/8" chip	sand
	6	37%	---	24%	39%
	8	35%	26%	---	39%
	9	25%	---	37%	38%
	10	43%	---	27%	30%
	11	20%	41%	---	39%
	12	15%	40%	---	45%
	13	35%	---	19%	46%
	14	26%	---	30%	44%
	15	32%	---	27%	41%
	20	15%	37%	---	48%
	21	41%	---	11%	48%
	25	Sieve sizes combined for optimum gradation			

Table 4. 8 – Shilstone Coarseness and Workability Values for Each Aggregate Blend

	Batch #											
	1,2	8	9	10	11	12	13	14	15	20	21	25
Coarseness	65.5	73.8	35.0	54.0	67.8	64.8	53.8	39.2	46.2	64.3	64.5	42.0
Workability	43.0	34.1	33.9	27.0	34.1	39.2	40.3	38.8	36.2	41.7	41.9	50.0

Figure 4. 2– Aggregate Blends Plotted on the Shilstone Target Zone



4.2.4.3 Dry-Rodded Unit Weight (DRUW)

The DRUW was performed on each of the aggregate blends as a form of quality check. This allowed physical data to display more closely the filling of the voids with varying particle sizes. The DRUW also allowed the investigators to have a visual check on the gradation. The results of this study are presented in Figure 4.3 and can be found in Table 4.3, 4.4, and 4.5 as well. The DRUW in relation with the Shilstone target zone has been provided in Figure 4.3.

Figure 4. 3 -- Dry-Rodded Unit Weight (Matrix 3 Aggregate Blends)

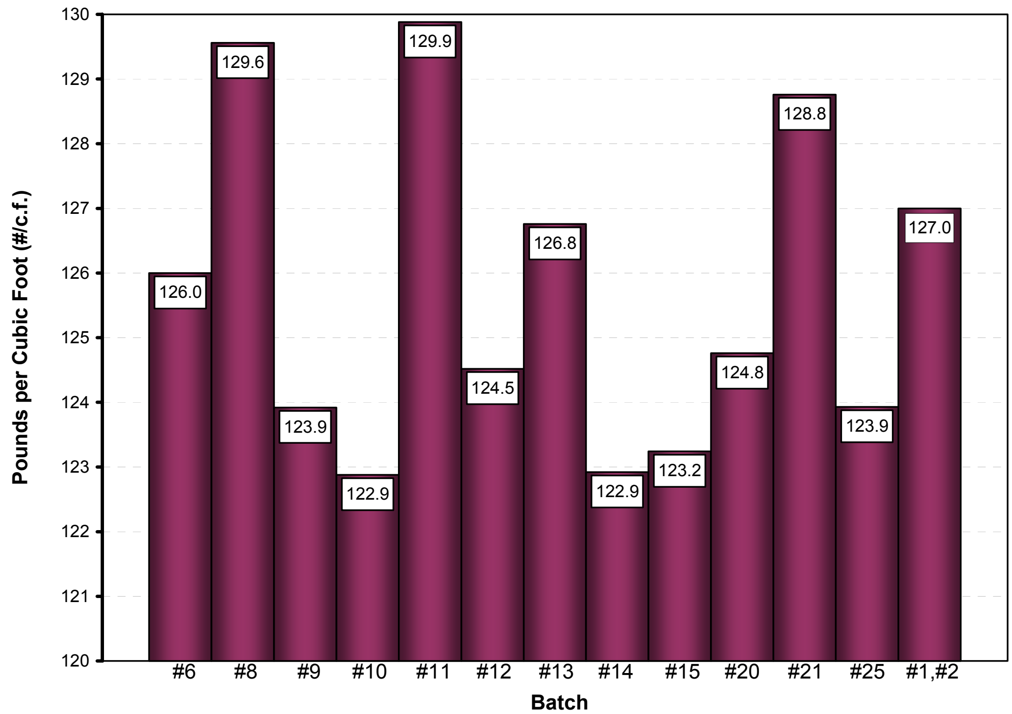
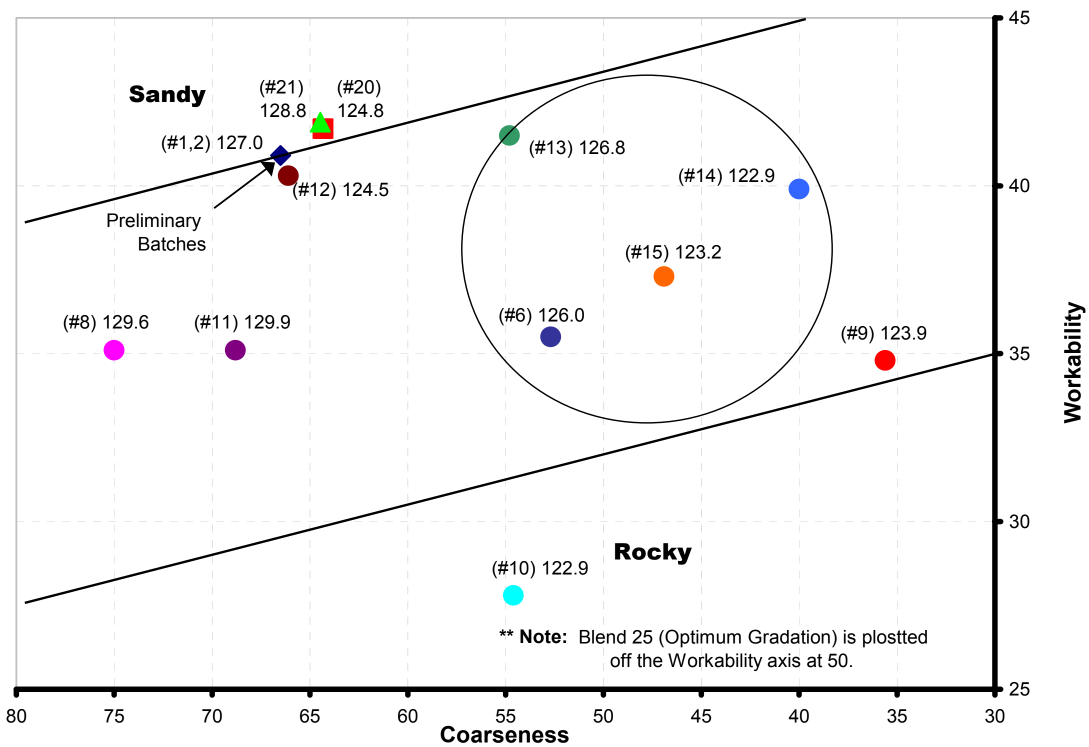


Figure 4. 4 – DRUW of Aggregate Blends on the Shilstone Target Zone



4.2.4.4 Percent Retained

An optimum aggregate blend is well-graded and contains no gaps within any particle sizes. For this reason the percent retained was looked at in this study as a method of finding a suitable particle distribution. Figures 4.5 thru 4.17 display the amounts retained per sieve for each of the blends in the investigation. The cream colored bars on either side of the sieve represent the low and high values provided by the primary investigator for this study due to prior aggregate studies research. The crimson bar in between these represents the actual sieve gradation for the given blend. The recommended sieve low and high values are as follows:

- **1.5 in (38.1 mm)** **Low:** N/A **High:** N/A
- **1 in (25.4 mm)** **Low:** 2.0% **High:** 6.0%
- **¾ in (19.1 mm)** **Low:** 5.0% **High:** 22.0%
- **½ in (12.7 mm)** **Low:** 8.0% **High:** 22.0%
- **$^{3}/_{8}$ in (9.53 mm)** **Low:** 8.0% **High:** 22.0%
- **#4 (4.75 mm)** **Low:** 8.0% **High:** 22.0%
- **#8 (2.36 mm)** **Low:** 8.0% **High:** 22.0%
- **#16 (1.18 mm)** **Low;** 8.0% **High:** 22.0%
- **#30 (0.600 mm)** **Low:** 8.0% **High:** 15.0%
- **#50 (0.300 mm)** **Low:** 5.0% **High:** 15.0%
- **#100 (0.150 mm)** **Low:** 0.0% **High:** 15.0%
- **#200 (0.075 mm)** **Low:** N/A **High:** N/A

Figure 4. 5 – Percent Retained per Sieve (Batches 1 and 2)

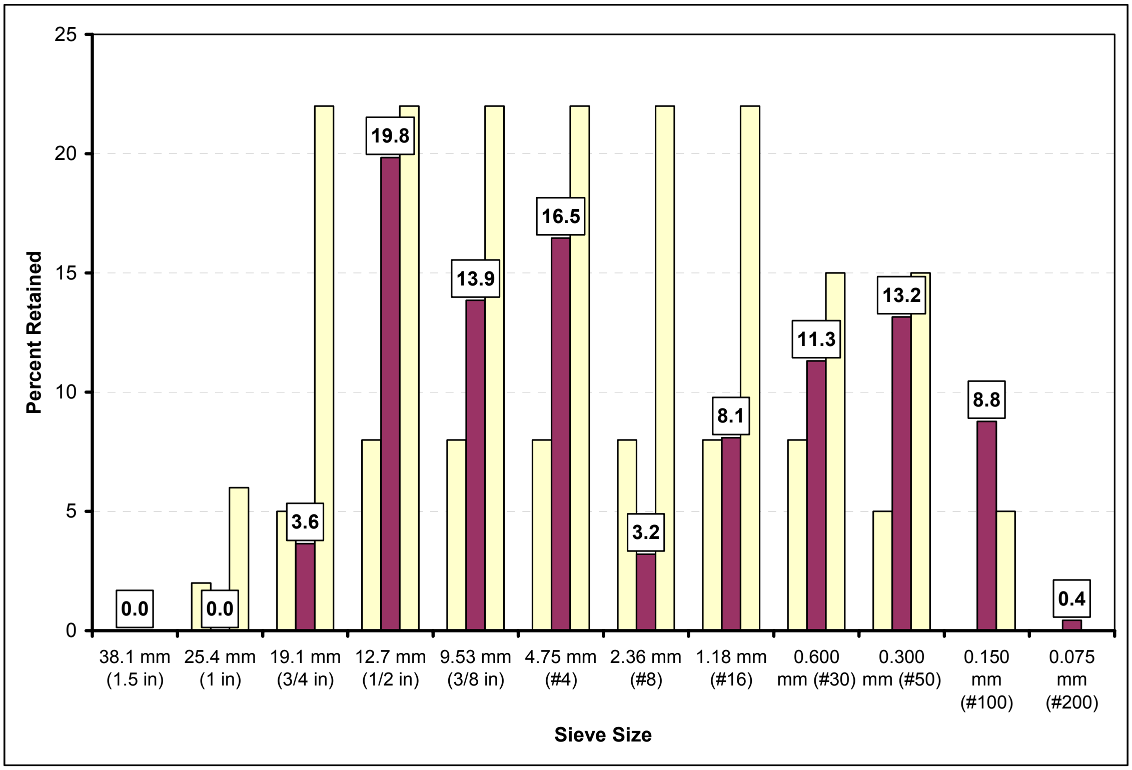


Figure 4. 6 – Percent Retained per Sieve (Batch 6)

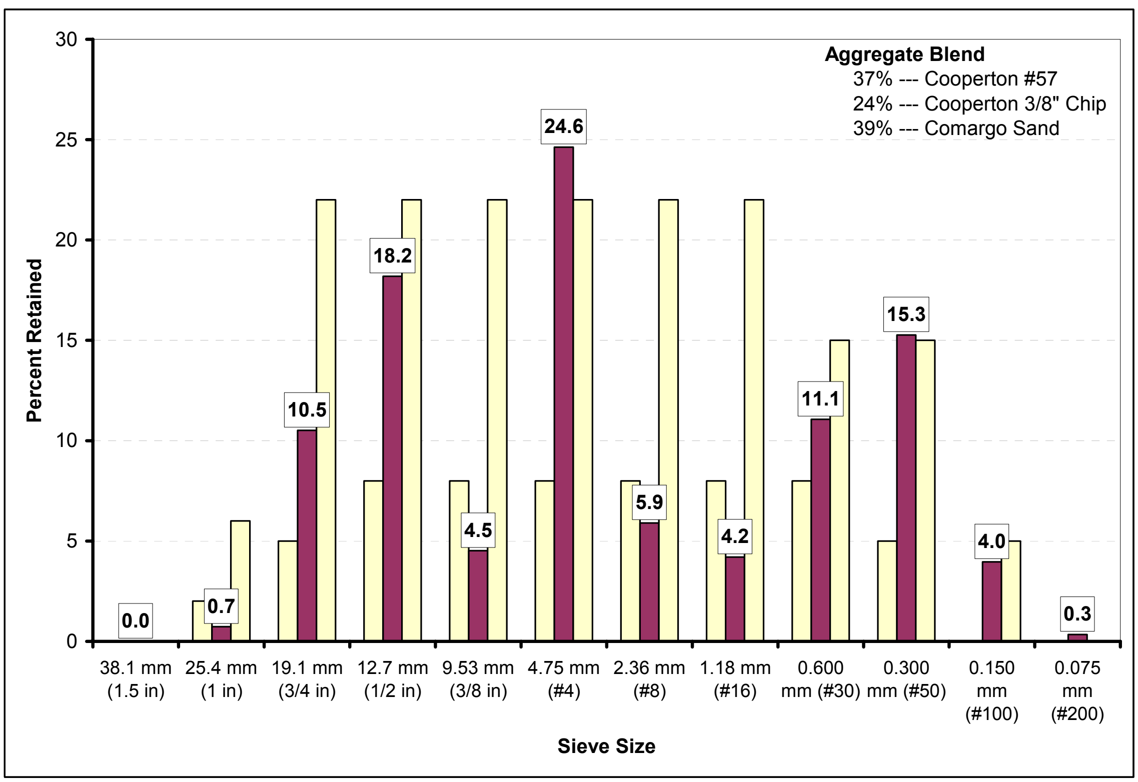


Figure 4. 7 – Percent Retained per Sieve (Batch 8)

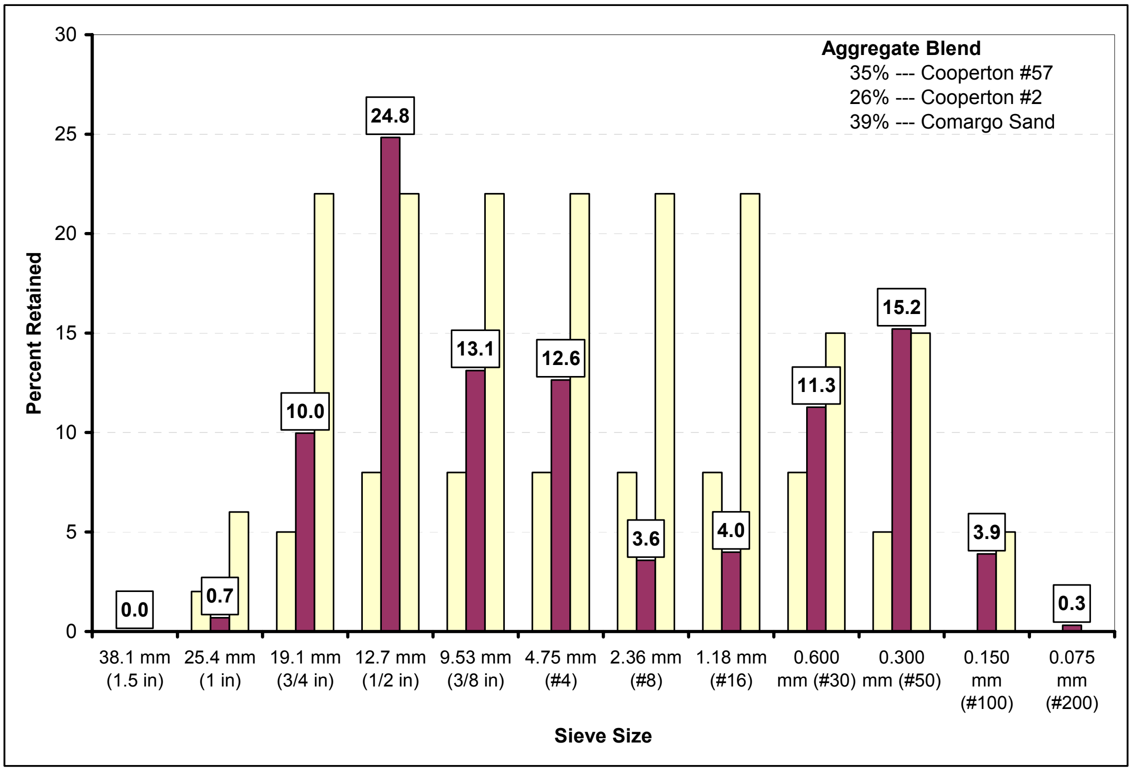


Figure 4. 8 – Percent Retained per Sieve (Batch 9)

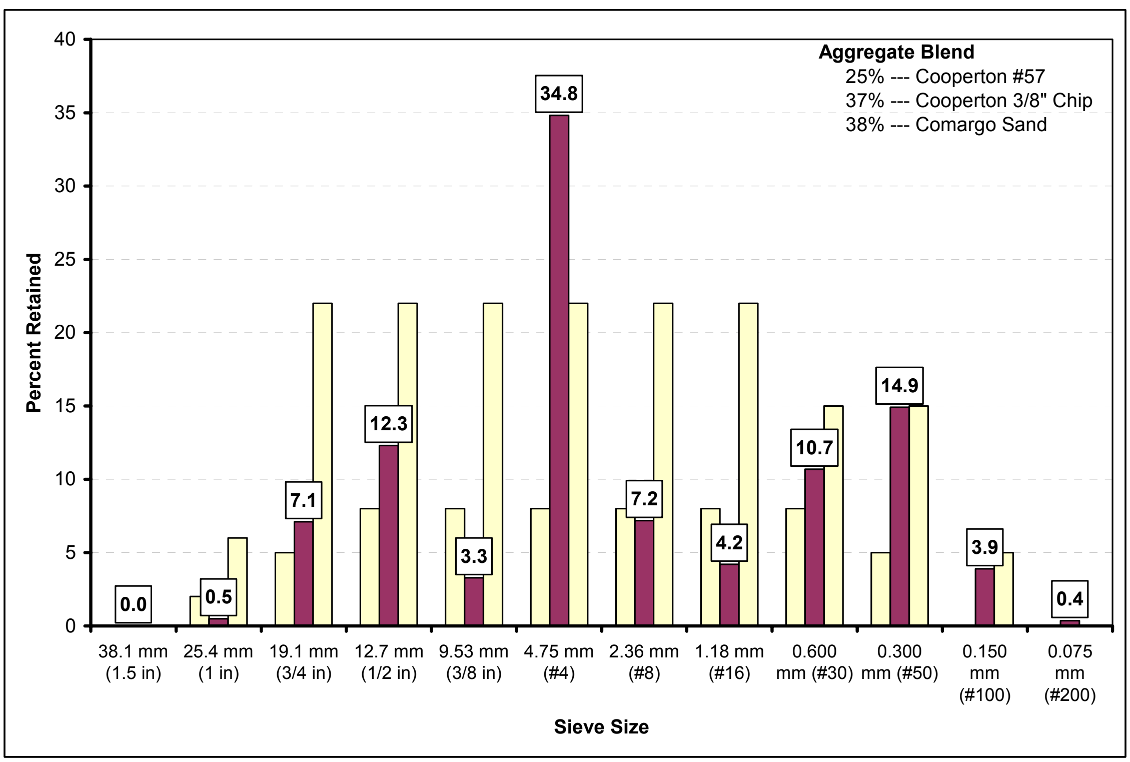


Figure 4. 9 – Percent Retained per Sieve (Batch 10)

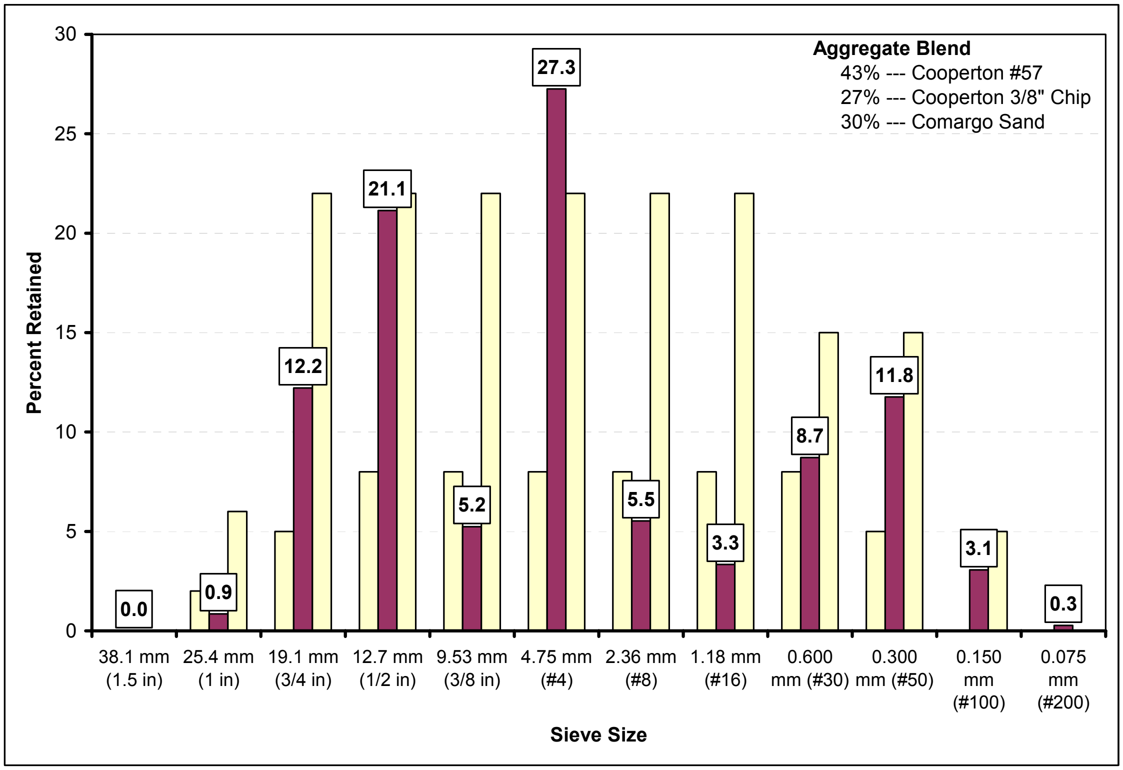


Figure 4. 10 – Percent Retained per Sieve (Batch 11)

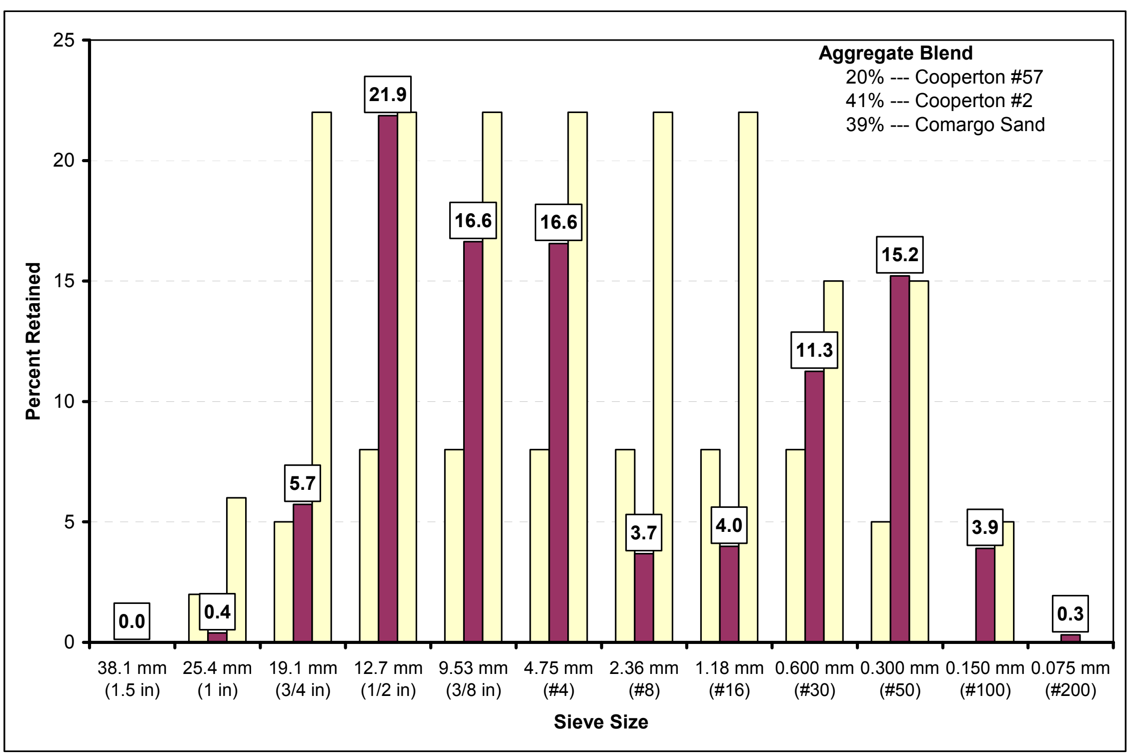


Figure 4. 11 – Percent Retained per Sieve (Batch 12)

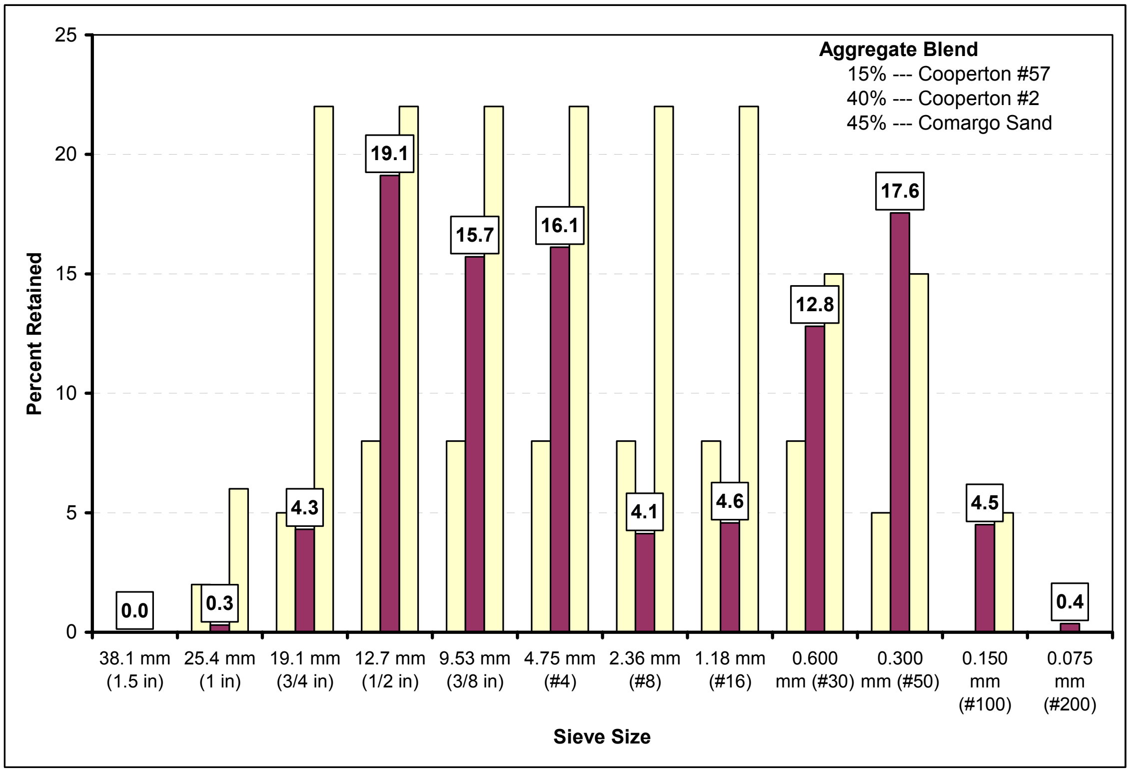


Figure 4. 12 – Percent Retained per Sieve (Batch 13)

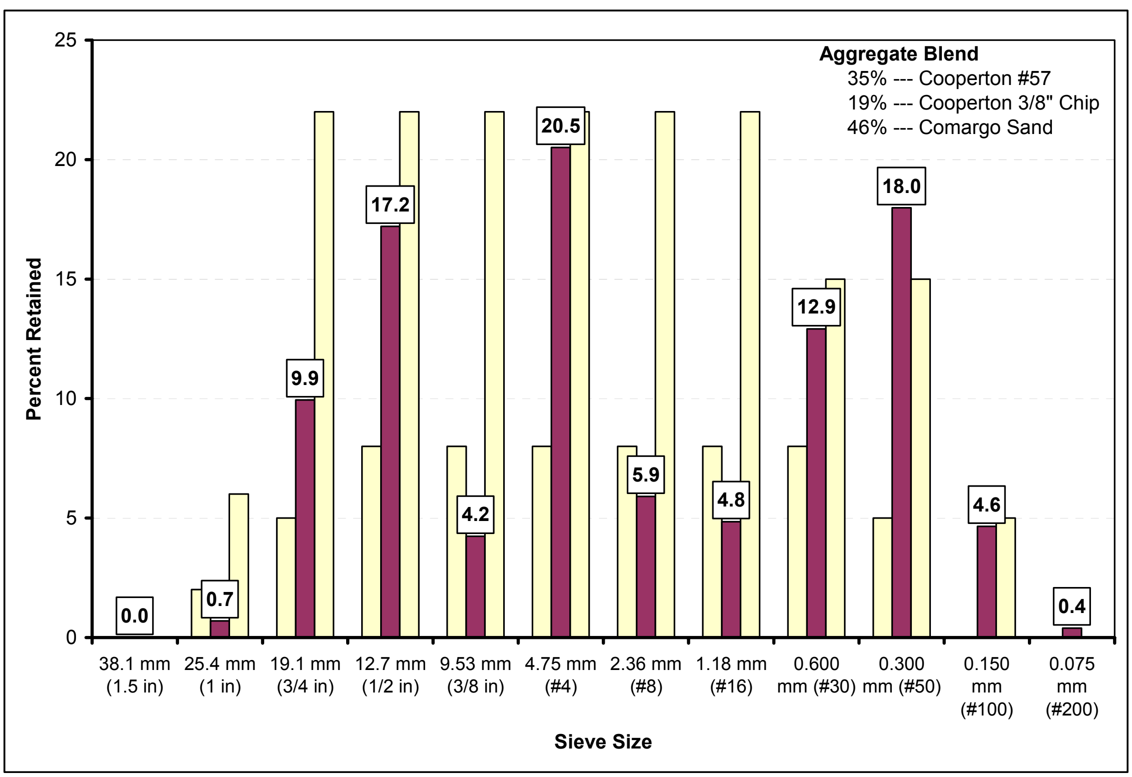


Figure 4. 13 – Percent Retained per Sieve (Batch 14)

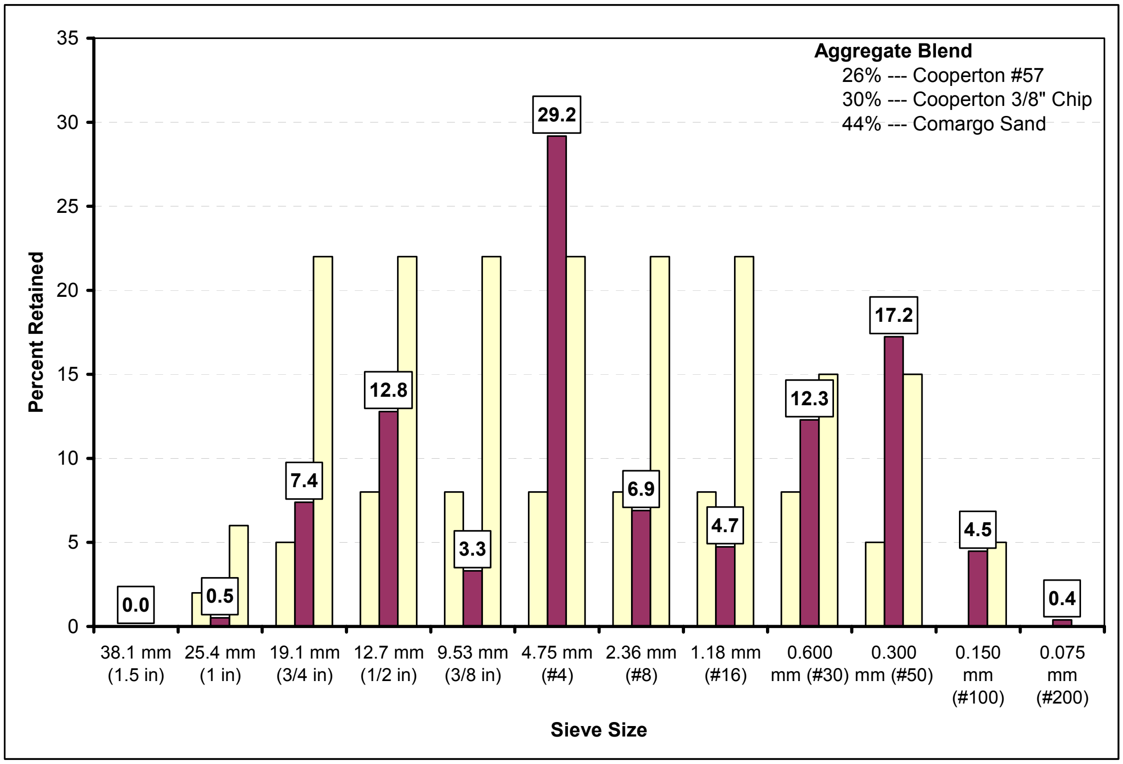


Figure 4. 14 – Percent Retained per Sieve (Batch 15)

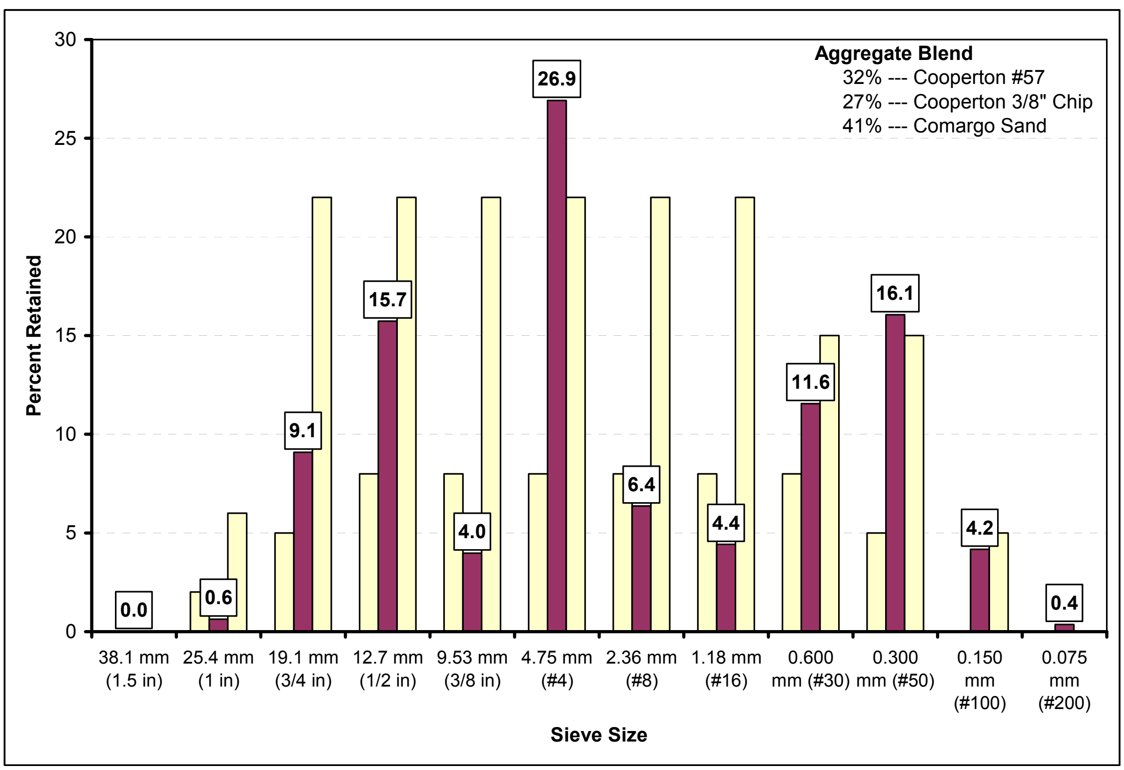


Figure 4. 15 – Percent Retained per Sieve (Batch 20)

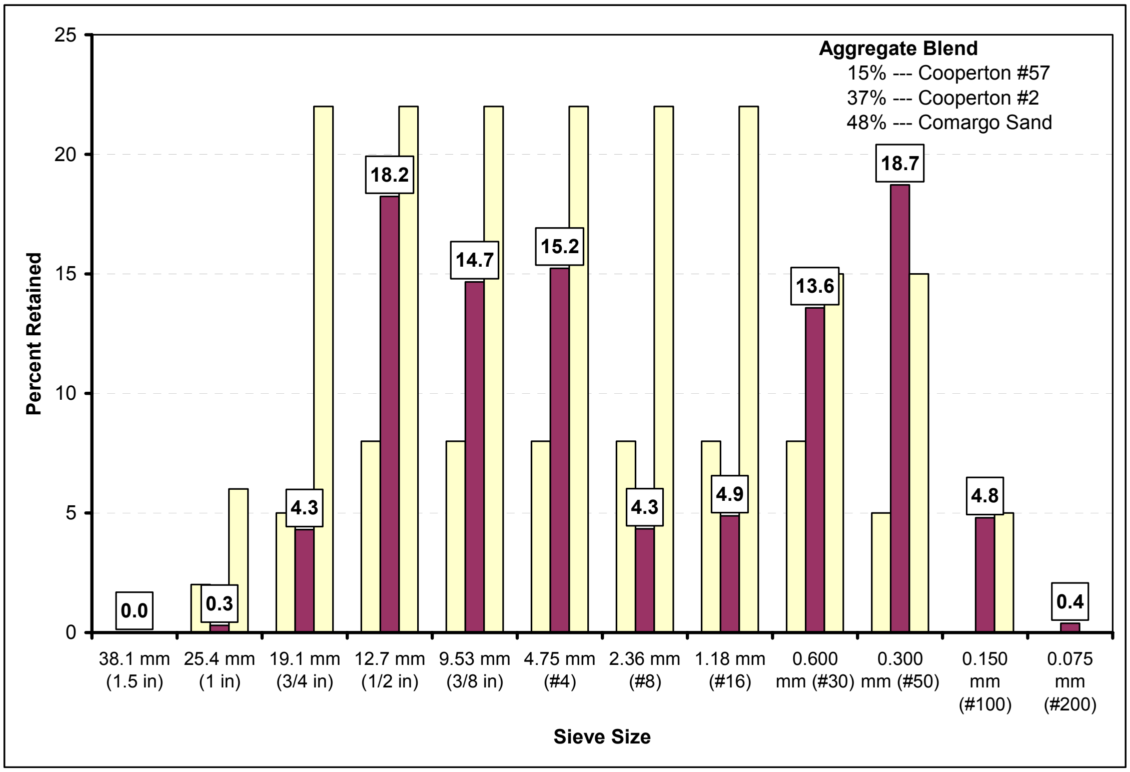


Figure 4. 16 – Percent Retained per Sieve (Batch 21)

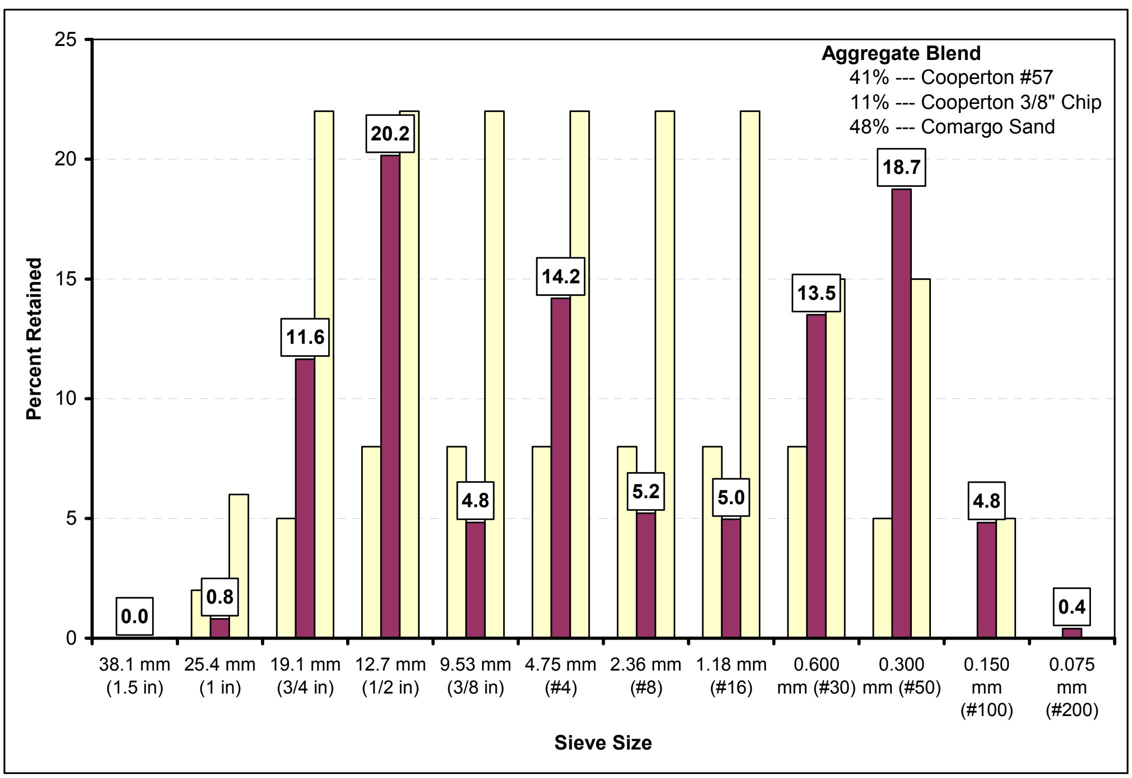
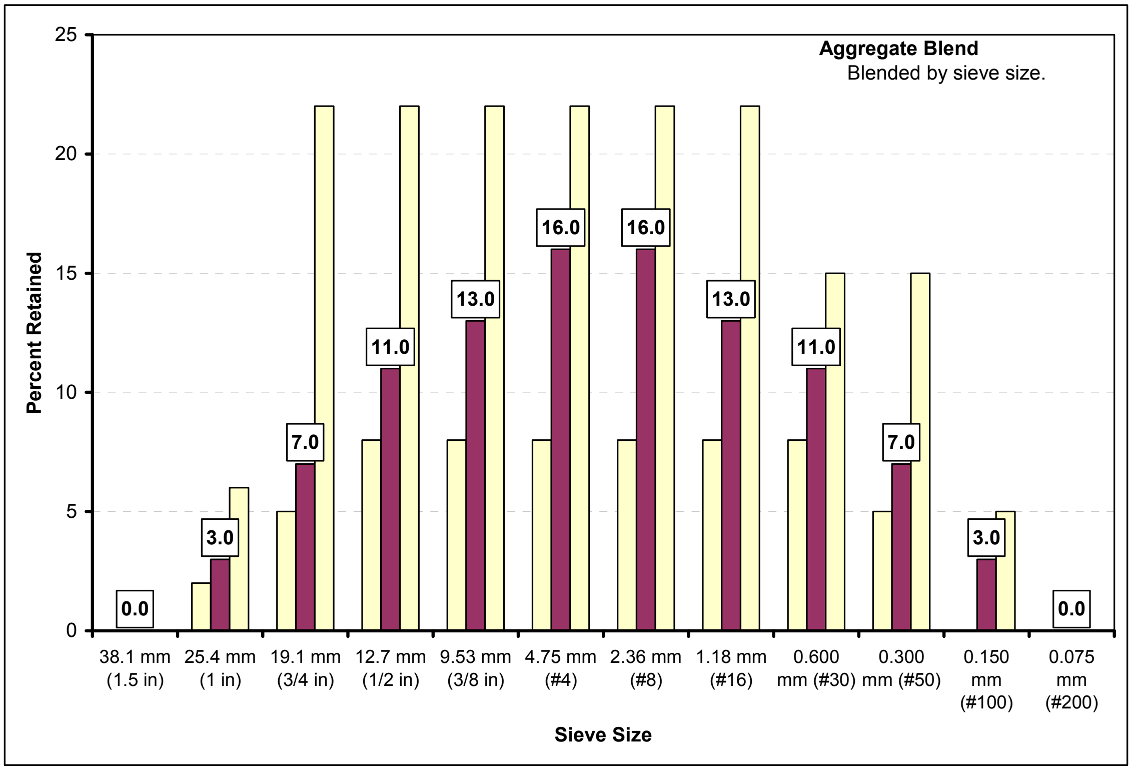


Figure 4. 17 – Percent Retained per Sieve (Batch 25)



4.2.5 Matrix 4 (water to cementitious materials ratio)

The purpose of the study in Matrix 4 was to develop the appropriate ratio of water to cementitious materials (w/cm) for the investigation. This was done by using a cementitious materials blend of 80% cement and 20% fly ash for each batch just as in the previous matrices. This proportioning led to the total cement and fly ash of 458.6 lb/yd^3 (272.0 kg/m^3) and 114.6 lb/yd^3 (68.0 kg/m^3), respectively. For this study, the mid-range water-reducer was set at a rate of 10.3 fl oz/cwt (6.0 mL/kg) and the air-entrainer dosage rate at 3.4 fl oz/cwt (2.0 mL/kg). The Batch 15 aggregate blend was chosen from Matrix 3 to continue Matrix 4 before the actual completion of Matrix 3. Thus, the final aggregate blend changed after the completion of Matrix 4; however, theoretically blend 15 should be optimum according to the Shilstone Coarseness Factor chart.

The amount of water in a concrete mixture is closely related to the strength and volumetric changes of the concrete. This is one reason why most HPC are developed with low ratios. This study began with Batch 15 which was created with the w/cm used up to this point of 0.38. This value was deemed to be appropriate by the primary investigator and his prior experience. After experience in this research, it was not viewed to be valuable to lower this ratio for workability reasons. Thus, Batches 16 and 17 of this study were increased to 0.40 and 0.42, respectively. Table 4.9 contains the mix proportions and design information as well as fresh and hardened concrete properties for Matrix 4.

Table 4. 9 – Fresh and Hardened Properties of Matrix 4 (w/cm ratio)

			Matrix 4 - w/cm		
			Batch # =		
			15	**16**	**17**
MIX PROPORTIONS (SSD AGGREGATES)	Cement	lb/yd^3 (kg/m^3)	458.6 (272.0)	458.6 (272.0)	458.6 (272.0)
	Fly Ash	lb/yd^3 (kg/m^3)	114.6 (68.0)	114.6 (68.0)	114.6 (68.0)
	Cooperton Coarse Aggregate (#57)	lb/yd^3 (kg/m^3)	969.5 (575.0)	959.7 (569.2)	950.1 (563.5)
	Cooperton Intermediate Aggregate (3/8" Chip)	lb/yd^3 (kg/m^3)	818.0 (485.2)	809.8 (480.3)	801.5 (475.4)
	Comargo Sand	lb/yd^3 (kg/m^3)	1,242.1 (736.7)	1,229.6 (729.3)	1,217.1 (721.9)
	Mixing Water	lb/yd^3 (kg/m^3)	215.1 (127.6)	226.6 (134.4)	238.1 (141.2)
	Air-Entrainer (MB AE™90)	fl.oz/yd^3 (mL/m^3)	17.6 (680.0)	17.6 (680.0)	17.6 (680.0)
	Mid-Range Water-Reducer (Polyheed® 1020)	fl.oz/yd^3 (mL/m^3)	52.7 (2,040.0)	52.7 (2,040.0)	52.7 (2,040.0)
DESIGN INFORMATION	Specific Gravity (Coarse and Inter. Aggregates)		2.67	2.67	2.67
	Specific Gravity (Sand)		2.63	2.63	2.63
	w/cm		**0.380**	**0.400**	**0.420**
	w/c		0.475	0.500	0.525
	Supplemental Cem. Mat. / Total Cem. Mat.	%	20.0	20.0	20.0
	Paste Content (by Vol.)	%	24.28	24.96	25.64
	Aggregate Content (by Vol.)	%	67.72	67.04	66.36
	Designed Air Content (by Vol.)	%	8.00	8.00	8.00
	Total (by Vol.)	%	100.00	100.00	100.00
BATCH DATA	Calculated Unit Weight	lb/yd^3 (kg/m^3)	3,823 (2,628)	3,804 (2,256)	3,786 (2,245)
	Measured Unit Weight	lb/yd^3 (kg/m^3)	3,989 (2,366)	3,715 (2,204)	3,631 (2,154)
	Yield	yd^3 (m^3)	0.96 (0.96)	1.03 (1.03)	1.04 (1.04)
	Dry Rodded Unit Weight	lb/yd^3 (kg/m^3)	3,327 (1,974)	3,327 (1,974)	3,327 (1,974)
	Air Temperature	^{o}F (^{o}C)	92 (33.3)	96 (35.6)	93 (33.9)
	Relative Humidity	%	41	35	39
	Concrete Temperature	^{o}F (^{o}C)	88 (31.1)	88 (30.8)	88 (31.1)
	Slump	inches (mm)	1.13 (29)	2.88 (73)	2.25 (57)
	Air Content (by Vol.)	%	5.1	9.3	11.5
	Hardened Properties:				
	Compressive Strength 24 hours	psi (Mpa)	2291 (16)	1155 (8)	1109 (8)
	3 days	psi (Mpa)	4220 (29)	2175 (15)	2249 (16)
	28 days	psi (Mpa)	5022 (35)	2604 (18)	2232 (15)
	56 days	psi (Mpa)	4839 (33)	2495 (17)	2022 (14)
	Shrinkage 28 days	in^{-6}/in (m^{-6}/m)	315 (315)	415 (415)	357 (357)
	Modulus of Elasticity 28 days	psi (Mpa)	3.81x106 (26,245)	2.62x10^6 (18,099)	2.47x10^6 (17,029)

4.2.6 Matrix 5 (Supplemental Cementitious Materials)

The purpose of Matrix 5 was to see the affects of supplemental cementitious materials on the HPC mixtures. To do this, two cementitious materials, fly ash and slag, were analyzed through four different combinations and proportions with the Type II cement. The first, Batch 16, was adopted into Matrix 5 from the previous Matrix 4. It consists of 80% cement and 20% fly ash. The next two batches, 18 and 19, include slag. Batch 18 consists of 50% cement and 50% slag. Fly ash was introduced in Batch 19 which consists of 50% cement, 20% fly ash, and 30% slag. Batch 22, 100% cement, was performed for comparative purposes.

For all of the batches in this matrix, a cementitious materials content of 573.2 lb/yd^3 (340 kg/m^3) was used. In addition, all of the batches consist of a w/cm ratio of 0.40. A dosage rate of 10.3 fl oz/cwt (6.0 mL/kg) for the mid-range water reducer and 3.4 fl oz/cwt (2.0 mL/kg) for the air-entrainer were used as well. The fresh and hardened properties as well as the batch proportions and design for Matrix 5 are presented in Table 4.10.

Table 4. 10 – Fresh and Hardened Properties of Matrix 5 (Supplemental Cementitious Materials)

			Matrix 5 - Supplemental Cem. Materials			
			Batch # =			
			16	18	19	22
MIX PROPORTIONS (SSD AGGREGATES)	Cement	lb/yd^3 (kg/m^3)	**458.6 (272.0)**	**286.6 (170.0)**	**286.6 (170.0)**	**573.2 (340.0)**
	Fly Ash	lb/yd^3 (kg/m^3)	**114.6 (68.0)**	**---**	**114.6 (68.0)**	**---**
	Slag	lb/yd^3 (kg/m^3)	**---**	**286.6 (170.0)**	**172.0 (102.0)**	**---**
	Cooperton Coarse Aggregate (#57)	lb/yd^3 (kg/m^3)	959.7 (569.2)	959.7 (569.2)	955.8 (566.9)	966.2 (573.1)
	Cooperton Intermediate Aggregate (3/8" Chip)	lb/yd^3 (kg/m^3)	809.8 (480.3)	809.6 (480.2)	806.4 (478.3)	815.2 (483.5)
	Comargo Sand	lb/yd^3 (kg/m^3)	1,229.6 (729.3)	1,229.4 (729.2)	1,224.5 (726.3)	1,237.9 (734.2)
	Mixing Water	lb/yd^3 (kg/m^3)	226.6 (134.4)	226.6 (134.4)	226.6 (134.4)	226.6 (134.4)
	Air-Entrainer (MB AE™90)	fl.oz/yd^3 (mL/m^3)	17.6 (680.0)	17.6 (680.0)	17.6 (680.0)	17.6 (680.0)
	Mid-Range Water Reducer (Polyheed® 1020)	fl.oz/yd^3 (mL/m^3)	52.7 (2,040.0)	52.7 (2,040.0)	52.7 (2,040.0)	52.7 (2,040.0)
DESIGN INFORMATION	Specific Gravity (Coarse and Inter. Aggregates)		2.67	2.67	2.67	2.67
	Specific Gravity (Sand)		2.63	2.63	2.63	2.63
	w/cm		0.400	0.400	0.400	0.400
	w/c		0.500	0.800	0.800	0.400
	Supplemental Cem. Mat. / Total Cem. Mat.	%	**20.0**	**50.0**	**50.0**	**0.0**
	Paste Content (by Vol.)	%	24.96	24.97	25.24	24.51
	Aggregate Content (by Vol.)	%	67.04	67.03	66.76	67.49
	Designed Air Content (by Vol.)	%	8.00	8.00	8.00	8.00
	Total (by Vol.)	%	100.00	100.00	100.00	100.00
BATCH DATA	Calculated Unit Weight	lb/yd^3 (kg/m^3)	3,804 (2,256)	3,804 (2,256)	3,792 (2,249)	3,825 (2,268)
	Measured Unit Weight	lb/yd^3 (kg/m^3)	3,715 (2,204)	4,057 (2,406)	3,722 (2,207)	4,051 (2,403)
	Yield		1.03	0.94	1.02	0.94
	Dry Rodded Unit Weight	lb/yd^3 (kg/m^3)	3,327 (1,974)	3,327 (1,974)	3,327 (1,974)	3,327 (1,974)
	Air Temperature	°F (°C)	96 (35.6)	91 (32.8)	92 (33.3)	96 (35.6)
	Relative Humidity	%	35	40	38	41
	Concrete Temperature	°F (°C)	88 (30.8)	84 (28.9)	84 (28.9)	89 (31.7)
	Slump	inches (mm)	2.88 (73)	1 (25)	5.5 (140)	0.5 (13)
	Air Content (by Vol.)	%	9.3	4.6	9.75	6.0
	Hardened Properties:					
	Compressive Strength 24 hours	psi (Mpa)	1155 (8)	1318 (9)	335 (2)	3412 (24)
	3 days	psi (Mpa)	2175 (15)	4028 (28)	1611 (11)	4929 (34)
	28 days	psi (Mpa)	2604 (18)	5760 (40)	2065 (14)	5764 (40)
	56 days	psi (Mpa)	2495 (17)	5902 (41)	2005 (14)	5736 (40)
	Shrinkage 28 days	in^{-6}/in (m^{-6}/m)	415 (415)	240 (240)	340 (340)	350 (350)
	Modulus of Elasticity 28 days	psi (Mpa)	2.62x106 (18,099)	4.24x10^6 (29,242)	2.43x10^6 (16,736)	3.65x10^6 (25,192)

4.2.7 Matrix 6 (Fibers)

One aspect of the investigation was to provide two of the four HPC mixtures with fiber reinforcement. Matrix 6 was developed to observe the affects that the fibers will have on these HPC mixtures. The parameters of this study were established through consultation from additional researchers on fiber reinforced concrete being performed in parallel to this research at the Donald G. Fears Structural Laboratory. The recommended dosage of fibers supplied by these researchers was 0.33% of the total concrete volume to consist of Fibermesh ½" Stealth fibers. This correlates to a dosage rate of 5.1 lb/yd^3 (3 kg/m^3).

Matrix 6 consists of two batches. The first of which is Batch 21 from Matrix 4 (Aggregate Blend) which was thought to contain the characteristics desired at this point in the research. In addition, Batch 23 was created for the fibers study. This batch duplicates Batch 21 with an exception to the fibers. Each of the batches contains a cementitious materials blend of 80% cement and 20% fly ash with a resulting cement and fly ash quantity of 458.6 lb/yd^3 (272.0 kg/m^3) and 114.6 lb/yd^3 (68.0 kg/m^3), respectively. The mid-range water reducer was set at a rate of 10.3 fl oz/cwt (6.0 mL/kg) and the air-entrainer dosage rate at 3.4 fl oz/cwt (2.0 mL/kg). Table 4.11 contains the mix proportions and design information as well as fresh and hardened concrete properties for Matrix 6.

Table 4. 11 – Fresh and Hardened Properties of Matrices 6 (Fibers) and 7 (Shrinkage-Reducer (SRA))

			Matrix 6 - Fibers		Matrix 7 - SRA	
			Batch # =		Batch # =	
			21	23	21	24
MIX PROPORTIONS (SSD AGGREGATES)	Cement	lb/yd^3 (kg/m^3)	458.6 (272.0)	458.6 (272.0)	458.6 (272.0)	458.6 (272.0)
	Fly Ash	lb/yd^3 (kg/m^3)	114.6 (68.0)	114.6 (68.0)	114.6 (68.0)	114.6 (68.0)
	Cooperton Coarse Aggregate (#57)	lb/yd^3 (kg/m^3)	1,240.9 (736.0)	1,234.8 (732.4)	1,240.9 (736.0)	1,236.3 (733.3)
	Cooperton Intermediate Aggregate (3/8" Chip)	lb/yd^3 (kg/m^3)	332.8 (197.4)	331.3 (196.5)	332.8 (197.4)	331.8 (196.8)
	Comargo Sand	lb/yd^3 (kg/m^3)	1,452.7 (861.6)	1,445.6 (857.4)	1,452.7 (861.6)	1,447.4 (858.5)
	Fibers (Fibermesh 1/2" Stealth Fibers)	lb/yd^3 (kg/m^3)	---	5.1 (3.0)	---	---
	Mixing Water	lb/yd^3 (kg/m^3)	215.1 (127.6)	215.1 (127.6)	215.1 (127.6)	209.1 (124.0)
	Air-Entrainer (MB AE™90)	fl.oz/yd^3 (mL/m^3)	17.6 (680.0)	17.6 (680.0)	17.6 (680.0)	17.6 (680.0)
	Mid-Range Water-Reducer (Polyheed® 1020)	fl.oz/yd^3 (mL/m^3)	52.7 (2,040.0)	52.7 (2,040.0)	52.7 (2,040.0)	52.7 (2,040.0)
	Shrinkage-Reducer (Tetraguard® AS20)	fl.oz/yd^3 (mL/m^3)	---	---	---	155.1 (6,000.0)
DESIGN INFORMATION	Specific Gravity (Coarse and Inter. Aggregates)		2.67	2.67	2.67	2.67
	Specific Gravity (Sand)		2.63	2.63	2.63	2.63
	w/cm		0.380	0.380	0.380	0.380
	w/c		0.475	0.475	0.475	0.475
	Supplemental Cem. Mat. / Total Cem. Mat.	%	20.0	20.0	20.0	20.0
	Paste Content (by Vol.)	%	24.28	24.28	24.28	24.52
	Aggregate Content (by Vol.)	%	67.72	67.39	67.72	67.48
	Fibers Content (by Vol.)	%	---	0.33	---	---
	Designed Air Content (by Vol.)	%	8.00	8.00	8.00	8.00
	Total (by Vol.)	%	100.00	100.00	100.00	100.00
BATCH DATA	Calculated Unit Weight	lb/yd^3 (kg/m^3)	3,820 (2,266)	3,811 (2,260)	3,820 (2,266)	3,816 (2,263)
	Measured Unit Weight	lb/yd^3 (kg/m^3)	3,886 (2,305)	3,996 (2,370)	3,886 (2,305)	4,080 (2,420)
	Yield	yd^3 (m^3)	0.99 (0.99)	0.95 (0.95)	0.99 (0.99)	0.94 (0.94)
	Dry Rodded Unit Weight	lb/yd^3 (kg/m^3)	3,477 (2,062)	3,477 (2,062)	3,477 (2,062)	3,477 (2,062)
	Air Temperature	°F (°C)	90 (31.9)	94 (34.4)	90 (31.9)	94 (34.4)
	Relative Humidity	%	47	41	47	40
	Concrete Temperature	°F (°C)	85 (29.4)	89 (31.7)	85 (29.4)	87 (30.6)
	Slump	inches (mm)	0.75 (19)	0.25 (6)	0.75 (19)	2.25 (57)
	Air Content (by Vol.)	%	8.0	5.4	8.0	3.3
	Hardened Properties:					
	Compressive Strength 24 hours	psi (Mpa)	2011 (14)	2286 (16)	2011 (14)	2280 (16)
	3 days	psi (Mpa)	3431 (24)	4497 (31)	3431 (24)	4825 (33)
	28 days	psi (Mpa)	4006 (28)	5102 (35)	4006 (28)	6343 (44)
	56 days	psi (Mpa)	3804 (26)	5240 (36)	3804 (26)	6358 (44)
	Shrinkage 28 days	in^{-6}/in (m^{-6}/m)	318 (318)	247 (247)	318 (318)	187 (187)
	Modulus of Elasticity 28 days	psi (Mpa)	3.34x106 (23,054)	3.29x10^6 (22,679)	3.34x106 (23,054)	4.39x10^6 (30,248)

4.2.8 Matrix 7 (Shrinkage-Reducing Admixture)

Matrix 7 was developed to observe the affects of the shrinkage-reducing admixture Tetraguard® AS20 on the HPC mixtures. This was performed through the analysis of two different batches. The first of which consisted of Batch 21 from Matrix 4 (Aggregate Blend) which was deemed to contain the characteristics desired at this point in the research. The second batch, Batch 24, is an exact replica of Batch 21 with the addition of the Tetraguard®. The Tetraguard® was applied at a dosage rate of 155.1 fl oz/yd^3 (6.0 L/m^3) which is within the manufacturer's recommended levels.

Each of the batches contains a cementitious materials blend of 80% cement and 20% fly ash with a resulting cement and fly ash quantity of 458.6 lb/yd^3 (272.0 kg/m^3) and 114.6 lb/yd^3 (68.0 kg/m^3), respectively. The mid-range water-reducer was set at a rate of 10.3 fl oz/cwt (6.0 mL/kg) and the air-entrainer dosage rate at 3.4 fl oz/cwt (2.0 mL/kg). Table 4.11 on the previous page contains the mix proportions and design information as well as fresh and hardened concrete properties for Matrix 7.

4.3 Secondary Batching

The secondary batching consists of thirteen batches developed from either Batch 21 (with out shrinkage-reducer) or 24 (with shrinkage-reducer). The research performed in this batching can be broken down into three subsections defined as the 6% designed air group, 6% designed air with shrinkage-reducer, and the 8% designed air group. This section allows the empirical process and data obtained to be easily followed.

4.3.1 6% Designed Air Group

This group consists of three separate batches, 26 thru 28. These batches were based off of the results found with Batch 21 except for the designed air volume was lowered to 6% from 8%. A combination of cement and fly ash was used in an 80% and 20% proportioning, respectively. These proportions led to a total of 458.6 lb/yd^3 (272.0 kg/m^3) of cement and 114.6 lb/yd^3 (68.0 kg/m^3) of fly ash. In addition, the air-entrainer was set at a dosage rate of 3.4 fl oz/cwt (2.0 mL/m^3) and the w/cm was at 0.38. After observing the physical characteristics of Batch 21, Batch 26 was created with the mid-range water-reducer dosage rate raised to 12.0 fl oz/cwt (7.0 mL/m^3) to produce a larger slump.

Batch 27 was created to replicate Batch 26 with one difference. Half of the weight of water was created with the use of ice. This measure was taken to see the affect of the lower specified concrete temperature requested by ODOT. As for Batch 28, it was created exactly as Batch 27 with the exception of the air-entrainer dosage was cut in half. The reduced air-entrainer dosage rate was 1.7 fl oz/cwt (1.0 mL/m^3). Table 4.12 presents the batch proportions and design as well as the fresh and hardened properties for the three batches.

Table 4. 12 – Fresh and Hardened Properties of 6% Designed Air Group

			6% Air Group		
			Batch # =		
			26	27	28
MIX PROPORTIONS (SSD AGGREGATES)	Cement	lb/yd^3 (kg/m^3)	458.6 (272.0)	458.6 (272.0)	458.6 (272.0)
	Fly Ash	lb/yd^3 (kg/m^3)	114.6 (68.0)	114.6 (68.0)	114.6 (68.0)
	Cooperton Coarse Aggregate (#57)	lb/yd^3 (kg/m^3)	1,276.7 (757.3)	1,276.7 (757.3)	1,277.5 (757.7)
	Cooperton Intermediate Aggregate (3/8" Chip)	lb/yd^3 (kg/m^3)	342.5 (203.2)	342.5 (203.2)	342.7 (203.3)
	Comargo Sand	lb/yd^3 (kg/m^3)	1,494.7 (886.6)	1,494.7 (886.6)	1,495.6 (887.1)
	Mixing Water	lb/yd^3 (kg/m^3)	215.1 (127.6)	215.1 (127.6)	215.1 (127.6)
	Air-Entrainer (MB AE™90)	fl.oz/yd^3 (mL/m^3)	17.6 (680.0)	17.6 (680.0)	8.8 (340.0)
	Mid-Range Water-Reducer (Polyheed® 1020)	fl.oz/yd^3 (mL/m^3)	61.5 (2,380.0)	61.5 (2,380.0)	61.5 (2,380.0)
	Shrinkage-Reducer (Tetraguard® AS20)	fl.oz/yd^3 (mL/m^3)	---	---	---
DESIGN INFORMATION	Specific Gravity (Coarse and Inter. Aggregates)		2.67	2.67	2.67
	Specific Gravity (Sand)		2.63	2.63	2.63
	w/cm		0.381	0.381	0.380
	w/c		0.476	0.476	0.475
	Supplemental Cem. Mat. / Total Cem. Mat.	%	20.0	20.0	20.0
	Paste Content (by Vol.)	%	24.32	24.32	24.28
	Aggregate Content (by Vol.)	%	69.68	69.68	69.72
	Designed Air Content (by Vol.)	%	6.00	6.00	6.00
	Total (by Vol.)	%	100.00	100.00	100.00
BATCH DATA	Calculated Unit Weight	lb/yd^3 (kg/m^3)	3,909 (2,318)	3,909 (2,318)	3,910 (2,319)
	Measured Unit Weight	lb/yd^3 (kg/m^3)	3,822 (2,267)	3,619 (2,146)	3,927 (2,329)
	Yield		1.02	1.08	1.00
	Dry Rodded Unit Weight	lb/yd^3 (kg/m^3)	3,477 (2,062)	3,477 (2,062)	3,477 (2,062)
	Air Temperature	°F (°C)	92 (33.3)	96 (35.6)	90 (32.2)
	Relative Humidity	%	49	44	48
	Concrete Temperature	°F (°C)	86 (30.0)	78 (25.6)	80 (26.7)
	Slump	inches (mm)	1.75 (44)	3.75 (95)	1.25 (32)
	Air Content (by Vol.)	%	5.0	11.0	5.1
	Hardened Properties:				
	Compressive Strength 24 hours	psi (Mpa)	1703 (12)	1112 (8)	1815 (13)
	3 days	psi (Mpa)	3089 (21)	1982 (14)	3651 (25)
	28 days	psi (Mpa)	3251(22)	1798 (12)	3887 (27)
	56 days	psi (Mpa)	3466 (24)	1997 (14)	3797 (26)
	Shrinkage 28 days	in^{-6}/in (m^{-6}/m)	283 (283)	337 (337)	243 (243)
	Modulus of Elasticity 28 days	psi (Mpa)	3.19x10^6 (21,975)	2.60x10^6 (17,901)	3.56x10^6 (24,530)

4.3.2 6% Designed Air with Shrinkage-Reducer (SRA) Group

Building from Batch 24 and the 6% Designed Air Group, the three batches in this group were performed to test the reaction of the shrinkage-reducer a little closer. In each of these batches, the designed air volume was held constant from the prior group at 6% air as was the 80% cement and 20% fly ash cementitious materials content. This developed a total cement content of 458.6 lb/yd^3 (272.0 kg/m^3) and a fly ash content of 114.6 lb/yd^3 (68.0 kg/m^3). The same dosage rate for the shrinkage-reducer was held constant from Batch 24 at 155.1 fl oz/yd^3 (6.0 L/m^3) and the w/cm was set at 0.38.

Batches 29, 30, and 32 of this group were designed exactly the same. All of the batches have an increased air-entrainer dosage rate of 5.2 fl oz/cwt (3.0 mL/kg) and a decreased mid-range water-reducer dosage rate of 10.3 fl oz/cwt (6.0 mL/kg). The variable between batches 29 and 30 is found in the addition of ice for half the weight of water in Batch 30, which was held constant for the rest of the research. Batch 32 was performed exactly as 30 with the exception of the timing of the addition of the shrinkage-reducer and air-entrainer. The reducer was added during the last minute of the mixing cycle where the air-entrainer addition was added with the aggregates at the beginning of the mixing cycle. These additions were held constant for the remainder of the research. Table 4.13 presents the batch proportions and design as well as the fresh and hardened properties for the three batches.

Table 4. 13 – Fresh and Hardened Properties

of the 6% Designed Air Group with Shrinkage-Reducer

			6% Air Group w/ SRA		
			Batch # =		
			29	30	32
MIX PROPORTIONS (SSD AGGREGATES)	Cement	lb/yd^3 (kg/m^3)	458.6 (272.0)	458.6 (272.0)	458.6 (272.0)
	Fly Ash	lb/yd^3 (kg/m^3)	114.6 (68.0)	114.6 (68.0)	114.6 (68.0)
	Cooperton Coarse Aggregate (#57)	lb/yd^3 (kg/m^3)	1,272.5 (754.8)	1,272.5 (754.8)	1,272.5 (754.8)
	Cooperton Intermediate Aggregate (3/8" Chip)	lb/yd^3 (kg/m^3)	341.4 (202.5)	341.4 (202.5)	341.4 (202.5)
	Comargo Sand	lb/yd^3 (kg/m^3)	1,489.8 (883.6)	1,489.8 (883.6)	1,489.8 (883.6)
	Mixing Water	lb/yd^3 (kg/m^3)	208.9 (123.9)	208.9 (123.9)	208.9 (123.9)
	Air-Entrainer (MB AE™90)	fl.oz/yd^3 (mL/m^3)	26.4 (1,020.0)	26.4 (1,020.0)	26.4 (1,020.0)
	Mid-Range Water-Reducer (Polyheed® 1020)	fl.oz/yd^3 (mL/m^3)	52.7 (2,040.0)	52.7 (2,040.0)	52.7 (2,040.0)
	Shrinkage-Reducer (Tetraguard® AS20)	fl.oz/yd^3 (mL/m^3)	155.1 (6,000.0)	155.1 (6,000.0)	155.1 (6,000.0)
DESIGN INFORMATION	Specific Gravity (Coarse and Inter. Aggregates)		2.67	2.67	2.67
	Specific Gravity (Sand)		2.63	2.63	2.63
	w/cm		0.380	0.380	0.380
	w/c		0.476	0.475	0.476
	Supplemental Cem. Mat. / Total Cem. Mat.	%	20.0	20.0	20.0
	Paste Content (by Vol.)	%	24.55	24.55	24.39
	Aggregate Content (by Vol.)	%	69.45	69.45	67.61
	Designed Air Content (by Vol.)	%	6.00	6.00	6.00
	Total (by Vol.)	%	100.00	100.00	100.00
BATCH DATA	Calculated Unit Weight	lb/yd^3 (kg/m^3)	3,904 (2,316)	3,904 (2,316)	3,904 (2,316)
	Measured Unit Weight	lb/yd^3 (kg/m^3)	4,054 (2,405)	4,036 (2,394)	4,085 (2,423)
	Yield		0.96	0.97	0.96
	Dry Rodded Unit Weight	lb/yd^3 (kg/m^3)	3,477 (2,062)	3,477 (2,062)	3,477 (2,062)
	Air Temperature	^{o}F (^{o}C)	90 (32.2)	88 (31.1)	72 (22.2)
	Relative Humidity	%	50	54	88
	Concrete Temperature	^{o}F (^{o}C)	84 (28.9)	79 (26.1)	76 (24.4)
	Slump	inches (mm)	1.75 (44)	2.25 (57)	1 (25)
	Air Content (by Vol.)	%	3.4	3.8	3.3
	Hardened Properties:				
	Compressive Strength 24 hours	psi (Mpa)	2235 (15)	2003 (14)	2577 (18)
	3 days	psi (Mpa)	4131 (28)	4150 (29)	4852 (33)
	28 days	psi (Mpa)	5917 (41)	5521 (38)	6763 (47)
	56 days	psi (Mpa)	6366 (44)	5959 (41)	7198 (50)
	Shrinkage 28 days	in^{-6}/in (m^{-6}/m)	203 (203)	193 (193)	213 (213)
	Modulus of Elasticity 28 days	psi (Mpa)	4.19x10^6 (28,917)	4.28x10^6 (29,538)	4.69x10^6 (32,359)

4.3.3 8% Air Group

This group most closely represents the empirical process out of all the secondary batching groups. The seven batches contained in this group vary through different combinations of when the shrinkage-reducer is added as well as the dosage rate of the shrinkage-reducer, mid-range water-reducer, and the air-entrainer. However, throughout all of the batches, the total cementitious materials content of 573.2 lb/yd^3 (340.0 kg/m^3) was held constant which was divided into 80% cement and 20% fly ash. It should also be noted that the w/cm was set at 0.38 and ice was added for concrete temperature control throughout this group. The batch proportions as well as the fresh and hardened properties are presented in Tables 4.14 and 4.15. The sequence of batches is as follows:

- **Batch 31** was developed just as Batch 32 with the exception of the designed air volume. The 6% designed air volume was raised to 8%. This in turn was held constant for all of the batches in this group except for Batch 36. Also, the addition of the shrinkage-reducer was once again added with the cementitious materials for this batch only, but the air-entrainer was still added with aggregates. Batch 31 contained an air-entrainer and mid-range water-reducer dosage rates of 5.2 fl oz/cwt (3.0 mL/kg) and 10.3 fl oz/cwt (6.0 mL/kg), respectively. In addition, the shrinkage-reducer dosage was set at 155.1 fl oz/yd^3 (6.0 L/m^3).

Table 4. 14 – Fresh and Hardened Properties of 8% Designed Air Group (Part 1 of 2)

			8% Air Group			
			Batch # =			
			31	34	35	36
MIX PROPORTIONS (SSD AGGREGATES)	Cement	lb/yd^3 (kg/m^3)	458.6 (272.0)	458.6 (272.0)	458.6 (272.0)	458.6 (272.0)
	Fly Ash	lb/yd^3 (kg/m^3)	114.6 (68.0)	114.6 (68.0)	114.6 (68.0)	114.6 (68.0)
	Cooperton Coarse Aggregate (#57)	lb/yd^3 (kg/m^3)	1,235.9 (733.0)	1,238.8 (734.8)	1,235.8 (733.0)	1,107.6 (657.0)
	Cooperton Intermediate Aggregate (3/8" Chip)	lb/yd^3 (kg/m^3)	331.6 (196.7)	332.4 (197.1)	331.6 (196.7)	297.2 (176.3)
	Comargo Sand	lb/yd^3 (kg/m^3)	1,446.9 (858.2)	1,450.3 (860.2)	1,446.9 (858.2)	1,296.7 (769.1)
	Mixing Water	lb/yd^3 (kg/m^3)	208.9 (123.9)	212.9 (126.3)	208.9 (123.9)	208.9 (123.9)
	Air-Entrainer (MB AE™90)	$fl.oz/yd^3$ (mL/m^3)	26.4 (1,020.0)	26.4 (1,020.0)	26.4 (1,020.0)	26.4 (1,020.0)
	Mid-Range Water-Reducer (Polyheed® 1020)	$fl.oz/yd^3$ (mL/m^3)	52.7 (2,040.0)	52.7 (2,040.0)	52.7 (2,040.0)	52.7 (2,040.0)
	Shrinkage-Reducer (Tetraguard® AS20)	$fl.oz/yd^3$ (mL/m^3)	155.1 (6,000.0)	51.7 (2,000.0)	155.1 (6,000.0)	155.1 (6,000.0)
DESIGN INFORMATION	Specific Gravity (Coarse and Inter. Aggregates)		2.67	2.67	2.67	2.67
	Specific Gravity (Sand)		2.63	2.63	2.63	2.63
	w/cm		0.380	0.380	0.380	0.380
	w/c		0.476	0.476	0.476	0.475
	Supplemental Cem. Mat. / Total Cem. Mat.	%	20.0	20.0	20.0	20.0
	Paste Content (by Vol.)	%	24.55	24.39	24.55	24.55
	Aggregate Content (by Vol.)	%	67.45	67.61	67.45	60.45
	Designed Air Content (by Vol.)	%	8.00	8.00	8.00	15.00
	Total (by Vol.)	%	100.00	100.00	100.00	100.00
BATCH DATA	Calculated Unit Weight	lb/yd^3 (kg/m^3)	3,815 (2,263)	3,818 (2,264)	3,815 (2,263)	3,502 (2,077)
	Measured Unit Weight	lb/yd^3 (kg/m^3)	4,075 (2,417)	3,846 (2,281)	4,073 (2,416)	4,037 (2,394)
	Yield		0.94	0.99	0.94	0.87
	Dry Rodded Unit Weight	lb/yd^3 (kg/m^3)	3,477 (2,062)	3,477 (2,062)	3,477 (2,062)	3,477 (2,062)
	Air Temperature	^oF (^oC)	82 (27.8)	N/R	78 (25.6)	78 (25.6)
	Relative Humidity	%	87	N/R	76	76
	Concrete Temperature	^oF (^oC)	80 (26.7)	N/R	80 (26.7)	80 (26.7)
	Slump	inches (mm)	1.5 (38)	3.3 (83)	1.3 (32)	5.0 (127)
	Air Content (by Vol.)	%	3.0	3.0	4.0	3
	Hardened Properties:					
	Compressive Strength — 24 hours	psi (Mpa)	2776 (19)	1520 (10)	1807 (12)	1968 (14)
	3 days	psi (Mpa)	5103 (35)	2869 (20)	3981 (27)	4213 (29)
	28 days	psi (Mpa)	6680 (46)	3763 (26)	5338 (37)	6236 (43)
	56 days	psi (Mpa)	6964 (48)	3817 (26)	5871 (40)	6096 (42)
	Shrinkage — 28 days	in^{-6}/in (m^{-6}/m)	190 (190)	290 (290)	203 (203)	177 (177)
	Modulus of Elasticity — 28 days	psi (Mpa)	$4.62x10^6$ (31,842)	$2.62x10^6$ (18,093)	$4.30x10^6$ (29,629)	$4.28x10^6$ (29,539)

Table 4. 15 – Fresh and Hardened Properties of 8% Designed Air Group (Part 2 of 2)

			8% Air Group (continued...)		
			Batch # =		
			37	38	39
MIX PROPORTIONS (SSD AGGREGATES)	Cement	lb/yd^3 (kg/m^3)	458.6 (272.0)	458.6 (272.0)	458.6 (272.0)
	Fly Ash	lb/yd^3 (kg/m^3)	114.6 (68.0)	114.6 (68.0)	114.6 (68.0)
	Cooperton Coarse Aggregate (#57)	lb/yd^3 (kg/m^3)	1,239.7 (735.3)	1,239.7 (735.3)	1,239.2 (735.0)
	Cooperton Intermediate Aggregate (3/8" Chip)	lb/yd^3 (kg/m^3)	332.6 (197.3)	332.6 (197.3)	332.5 (197.2)
	Comargo Sand	lb/yd^3 (kg/m^3)	1,451.4 (860.9)	1,451.4 (860.9)	1,450.7 (860.5)
	Mixing Water	lb/yd^3 (kg/m^3)	214.1 (127.0)	214.1 (127.0)	213.4 (126.6)
	Air-Entrainer (MB AE™90)	fl.oz/yd^3 (mL/m^3)	35.2 (1,360.0)	44.2 (1,710.0)	52.7 (2,040.0)
	Mid-Range Water Reducer (Polyheed® 1020)	fl.oz/yd^3 (mL/m^3)	52.7 (2,040.0)	52.7 (2,040.0)	61.5 (2,380.0)
	Shrinkage-Reducer (Tetraguard® AS20)	fl.oz/yd^3 (mL/m^3)	12.9 (500.0)	3.9 (150.0)	3.9 (150.0)
DESIGN INFORMATION	Specific Gravity (Coarse and Inter. Aggregates)		2.67	2.67	2.67
	Specific Gravity (Sand)		2.63	2.63	2.63
	w/cm		0.380	0.380	0.380
	w/c		0.476	0.476	0.476
	Supplemental Cem. Mat. / Total Cem. Mat.	%	20.0	20.0	20.0
	Paste Content (by Vol.)	%	24.34	24.34	24.37
	Aggregate Content (by Vol.)	%	67.66	67.66	67.63
	Designed Air Content (by Vol.)	%	8.00	8.00	8.00
	Total (by Vol.)	%	100.00	100.00	100.00
BATCH DATA	Calculated Unit Weight	lb/yd^3 (kg/m^3)	3,819 (2,265)	3,819 (2,265)	3,818 (2,265)
	Measured Unit Weight	lb/yd^3 (kg/m^3)	3,832 (2,273)	4,029 (2,390)	N/R
	Yield		1.00	0.95	N/R
	Dry Rodded Unit Weight	lb/yd^3 (kg/m^3)	3,477 (2,062)	3,477 (2,062)	3,477 (2,062)
	Air Temperature	^{o}F (^{o}C)	N/R	92 (33.3)	92 (33.3)
	Relative Humidity	%	N/R	47	47
	Concrete Temperature	^{o}F (^{o}C)	80 (26.7)	80 (26.7)	80 (26.7)
	Slump	inches (mm)	2.3 (57)	0.0 (0.0)	0.0 (0.0)
	Air Content (by Vol.)	%	9.0	5.0	5.0
	Hardened Properties:				
	Compressive Strength 24 hours	psi (Mpa)	1547 (11)	2876 (20)	2567 (18)
	3 days	psi (Mpa)	2776 (19)	4817 (33)	4682 (32)
	28 days	psi (Mpa)	3406 (23)	6391 (44)	5919 (41)
	56 days	psi (Mpa)	3357 (23)	6005 (41)	5555 (38)
	Shrinkage 28 days	in^{-6}/in (m^{-6}/m)	397 (397)	240 (240)	260 (260)
	Modulus of Elasticity 28 days	psi (Mpa)	2.97x10^6 (20,501)	4.11x10^6 (28,354)	3.95x10^6 (27,219)

- **Batch 34** was developed with a decrease in dosage of the shrinkage-reducer. The shrinkage-reducer was still added at the end of the mixing cycle as in Batch 32; however, the dosage rate was changed to 51.7 fl oz/yd^3 (2.0 L/m^3).

- **Batch 35** was developed just as Batch 32 with an alteration in the addition of the shrinkage-reducer. The admixture was still added at the end of the mixing cycle; however, the air content, slump, and unit weight were taken prior. This left approximately a five minute mixing down time during the testing. The shrinkage-reducer was then added and mixed in the mixer for an additional minute.

- **Batch 36** is an exact replica of Batch 35 in terms of proportions, admixture additions, and testing. The change made was in the air volume designed for. The 8% design air in use was raised to 15% (the designed air increase only applied to Batch 36).

- **Batch 37** lowered the designed air content from Batch 36 back down to 8%. The dosage rate of the air-entrainer was also increased to 6.9 fl oz/cwt (4.0 mL/kg) and the shrinkage-reducer was lowered to 12.9 fl oz/yd^3 (500 mL/m^3). However, in the process of batching, the air content was taken throughout the process. The air was first recorded without the shrinkage-reducer. Then two approximately 1.0 fl oz/yd^3 (40 mL/m^3)

dosages of the shrinkage-reducer were added and air content readings were taken using the same 5 minute/1minute cycle as before. Thus, the designed 12.9 fl oz/yd^3 dosage was not followed.

- **Batch 38** was designed from the preceding Batch 37. The difference between the two is that the shrinkage-reducer was lowered even more to 3.9 fl oz/yd^3 (150 mL/m^3) and the air-entrainer was raised to a dosage rate of 8.6 fl oz/cwt (5.0 mL/kg). It should be noted that no additional air content readings were made in the batch.

- **Batch 39** and 38 are exactly alike except for the dosage rates of the mid-range water-reducer and the air-entrainer. These values are 12.0 fl oz/cwt (7.0 mL/kg) and 10.3 fl oz/cwt (6.0 mL/kg), respectively.

4.4 Final Batches

The final batches contain the four HPC mixtures that were developed for the product of the investigation. These include Batch 40 (cement + fly ash), 41 (cement only), 42 (cement + fly ash + fibers), and 43 (cement + fibers). For each of the batches the w/cm was set at 0.38 and the total cementitious materials content at 573.2 lb/yd^3 (340 kg/m^3). For Batches 40 and 42 the cementitious materials were divided into 80% cement and 20% fly ash where Batches 41 and 43 contained 100% cement. When fibers were used in Batches 42 and 43, the established dosage rate of 5.1 lb/yd^3 (3 kg/m^3) from Matrix 6 was used. For all of the batches, the shrinkage-reducer, air-entrainer, and mid-range water-reducer were held at 12.9 fl oz/yd^3 (500.0 mL/m^3), 6.9 fl oz/cwt (4.0 mL/kg), and 10.3 fl oz/cwt (6.0 mL/kg), respectively. However, it should be noted that the designed admixture dosage rates were not used in the actual mixing process for all of the batches. Each was mixed with a 5 minute rest then a 1 minute shrinkage-reducer mixing cycle to better monitor the air content levels created. Thus if the air content was too high, additional shrinkage-reducer dosages of the same size were added through the same 5 minute / 1 minute cycle to bring the air content down to a desirable level. This cycle addition was performed three times for Batch 40. Where the shrinkage-reducer could be used to bring the air content back down, the air-entrainer was varied to govern the air contents initially. As for the mid-range water-reducer, these values were altered to increase the overall workability from those seen with the designed dosage rate. The designed and actual dosage rates for each admixture in the final batches are displayed in Table 4.16.

Table 4. 16 – Admixture Dosage Rates for Final Batches

		Air-Entrainer		Mid-Range Water Reducer		Shrinkage-Reducer	
		Designed Amount fl oz/cwt (mL/kg)	Actual Amount fl oz/cwt (mL/kg)	Designed Amount fl oz/cwt (mL/kg)	Actual Amount fl oz/cwt (mL/kg)	Designed Amount fl oz/yd^3 (L/m^3)	Actual Addition fl oz/yd^3 (L/m^3)
Batch #	40	6.9 (4.0)	5.0 (2.9)	10.3 (6.0)	10.3 (6.0)	12.9 (0.5)	38.8 (1.5)
	41	6.9 (4.0)	8.3 (4.8)	10.3 (6.0)	5.0 (2.9)	12.9 (0.5)	12.9 (0.5)
	42	6.9 (4.0)	6.9 (4.0)	10.3 (6.0)	19.1 (11.1)	12.9 (0.5)	12.9 (0.5)
	43	6.9 (4.0)	5.0 (2.9)	10.3 (6.0)	8.3 (4.8)	12.9 (0.5)	12.9 (0.5)
	44	6.9 (4.0)	5.0 (2.9)	10.3 (6.0)	10.3 (6.0)	12.9 (0.5)	12.9 (0.5)

An additional batch, Batch 44, was performed to consider travel time of the mixing trucks in the field. This batch is a duplicate of Batch 40 with an additional mixing time of approximately forty minutes. However, only one 5 minutes / 1 minute shrinkage-reducer cycle was used prior to the forty minutes additional time. Table 4.17 contains the mix proportions and design information as well as fresh and hardened concrete properties for the Final Batches.

Table 4. 17 – Fresh and Hardened Properties of Final Batches

			Final Batches				
		Batch # =	40	41	42	43	44
MIX PROPORTIONS (SSD AGGREGATES)	Cement	lb/yd³ (kg/m³)	458.6 (272.0)	573.2 (340.0)	458.6 (272.0)	573.2 (340.0)	458.6 (272.0)
	Fly Ash	lb/yd³ (kg/m³)	114.6 (68.0)	---	114.6 (68.0)	---	114.6 (68.0)
	Cooperton Coarse Aggregate (#57)	lb/yd³ (kg/m³)	1,239.7 (735.3)	1,248.2 (740.3)	1,233.7 (731.7)	1,242.1 (736.7)	1,239.7 (735.3)
	Cooperton Intermediate Aggregate (3/8" Chip)	lb/yd³ (kg/m³)	332.6 (197.3)	334.9 (198.6)	331.0 (196.3)	333.3 (197.7)	332.6 (197.3)
	Comargo Sand	lb/yd³ (kg/m³)	1,451.5 (860.9)	1,461.3 (866.7)	1,444.3 (856.7)	1,454.2 (862.5)	1,451.5 (860.9)
	Fibers (Fibermesh 1/2" Stealth Fibers)	lb/yd³ (kg/m³)	---	---	5.1 (3.00)	5.1 (3.0)	---
	Mixing Water	lb/yd³ (kg/m³)	214.1 (127.0)	214.1 (127.0)	214.1 (127.0)	214.1 (127.0)	214.1 (127.0)
	Air-Entrainer (MB AE™90)	fl.oz/yd³ (mL/m³)	35.2 (1,360.0)	35.2 (1,360.0)	35.2 (1,360.0)	35.2 (1,360.0)	35.2 (1,360.0)
	Mid-Range Water-Reducer (Polyheed® 1020)	fl.oz/yd³ (mL/m³)	52.7 (2,040.0)	52.7 (2,040.0)	52.7 (2,040.0)	52.7 (2,040.0)	52.7(2,040.0)
	Shrinkage-Reducer (Tetraguard® AS20)	fl.oz/yd³ (mL/m³)	12.9 (500.0)	12.9 (500.0)	12.9 (500.0)	12.9 (500.0)	12.9 (500.0)
DESIGN INFORMATION	Specific Gravity (Coarse and Inter. Aggregates)		2.67	2.67	2.67	2.67	2.67
	Specific Gravity (Sand)		2.63	2.63	2.63	2.63	2.63
	w/cm		0.380	0.380	0.380	0.380	0.380
	w/c		0.476	0.380	0.476	0.380	0.476
	Supplemental Cem. Mat. / Total Cem. Mat.	%	20.0	0.0	20.0	0.0	20.0
	Paste Content (by Vol.)	%	24.34	23.88	24.34	23.88	24.34
	Aggregate Content (by Vol.)	%	67.66	68.12	67.33	67.79	67.66
	Fibers Content (by Vol.)	%	---	---	0.33	0.33	---
	Designed Air Content (by Vol.)	%	8.00	8.00	8.00	8.00	8.00
	Total (by Vol.)	%	100.00	100.00	100.00	100.00	100.00
BATCH DATA	Calculated Unit Weight	lb/yd³ (kg/m³)	3,819 (2,265)	3,840 (2,277)	3,809 (2,259)	3,830 (2,272)	3,819 (2,265)
	Measured Unit Weight	lb/yd³ (kg/m³)	3,992 (2,368)	4,029 (2,390)	4,053 (2,404)	4,020 (2,384)	3,938 (2,336)
	Yield	yd³ (m³)	0.96	0.95	0.94	0.95	0.97
	Dry Rodded Unit Weight	lb/yd³ (kg/m³)	3,477 (2,062)	3,477 (2,062)	3,477 (2,062)	3,477 (2,062)	3,477 (2,062)
	Air Temperature	°F (°C)	93 (33.9)	94 (34.4)	94 (34.4)	87 (30.6)	88 (31.1)
	Relative Humidity	%	50	49	47	58	39
	Concrete Temperature	°F (°C)	80 (26.7)	81 (27.2)	84 (28.9)	84 (28.9)	83 (28.3)
	Slump	inches (mm)	1.5 (38)	1.0 (25)	1.0 (25)	1.0 (25)	0.5 (13)
	Air Content (by Vol.)	%	6.7	5.8	5.0	5.5	5.5
	Hardened Properties:						
	Compressive Strength 24 hours	psi (Mpa)	3879 (27)	4113 (28)	841 (6)	2845 (20)	3966 (27)
	3 days	psi (Mpa)	4552 (31)	5267 (36)	4322 (30)	5340 (37)	5411 (37)
	28 days	psi (Mpa)	5617 (39)	6506 (45)	5303 (37)	6940 (48)	6746 (47)
	56 days	psi (Mpa)	5605 (39)	6749 (47)	5589 (39)	6807 (47)	N/R
	Shrinkage 28 days	in⁻⁶/in (m⁻⁶/m)	280 (280)	297 (297)	303 (303)	277 (277)	310 (310)
	Modulus of Elasticity 28 days	psi (Mpa)	3.07×10^6 (21,148)	4.35×10^6 (30,001)	3.92×10^6 (27,003)	3.83×10^6 (26,402)	3.27×10^6 (22,578)

4.5 Chapter Summary

This Chapter provides the data and results for the laboratory research performed throughout this investigation. It provides a discussion of the changes made throughout the batching sequence as it was performed through the primary investigation, secondary batching, and the final batches. The additional testing to be performed for the batch characterization, i.e. splitting tensile, freeze-thaw, and air void analysis, was not presented in this chapter. This is because these tests were performed during field investigations and are reported in Chapter 6.

CHAPTER 5 – Discussion of Results

5.1 Introduction

This chapter provides the discussion and logic behind the progression of the research. Explanations and reasoning for the development of the batch results and mix designs are offered. This is done through interpretation of the developed variables as well as the fresh and hardened concrete properties.

5.2 Primary Investigation

5.2.1 Matrix 1 (Air-Entrainer)

Matrix 1 was the beginning of the investigation using the local materials to be analyzed. For this many of the variables that were changed in succeeding batches were set at levels that were deemed reasonable by the primary investigator. This includes factors such as the w/cm, mid-range water-reducer dosage, cementitious materials content, and an aggregate blend that was chosen through the use of the Shilstone method prior to the blend investigation. Refer to Table 4.2 for the proportioning as well as the fresh and hardened concrete properties. With all of these variables, it was felt that the air-entrainer should be studied first. This was due to the levels of air required in the mixtures by ODOT and the low predictability of the amount of air that the entrainer will produce with the all the variables present. Thus, the batches were performed one without air-entrainer and one within the manufacturer's recommended dosage rate. The actual air-contents that these designs created during batching are as follows:

- **Batch 3 (w/ air-entrainer) = 10.5%**
- **Batch 4 (w/out) = 1.9%**

These levels of air found were to be predicted. Concrete, by nature, tends to produce approximately 2% entrapped air which was proven in Batch 4. As for Batch 3, a level of 8% was the designed air content. The 10.5% air actually measured did not meet this, but allowed the investigators to view the affects of the dosage rate with the materials and batching process used.

Additional observations made on the fresh concrete properties were those of the unit weight and slump. As expected the increased air lessened the unit weight and increased the slump, and in turn the air hurt the performance of the hardened concrete properties. Two of these are the compressive strength and shrinkage results. When air occupies more of the volume of concrete, the compressive strength tends to decrease and the amount of volumetric shrinkage will tend to increase. With the large difference between 10.5% and 1.9%, this effect is easily seen. Figures 5.1 and 5.2 graphically present the compressive strength and unrestrained length change data over a 56 day period for Matrix 1.

Figure 5. 1 – Compressive Strength of Matrix 1 (Air-Entrainer)

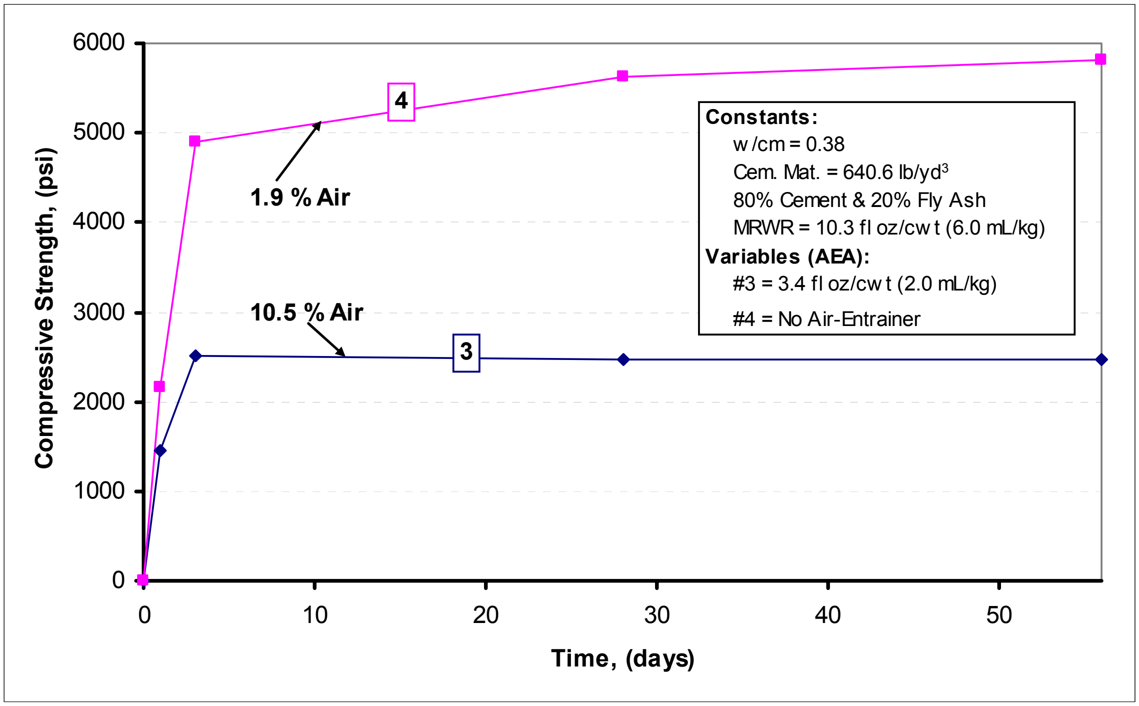
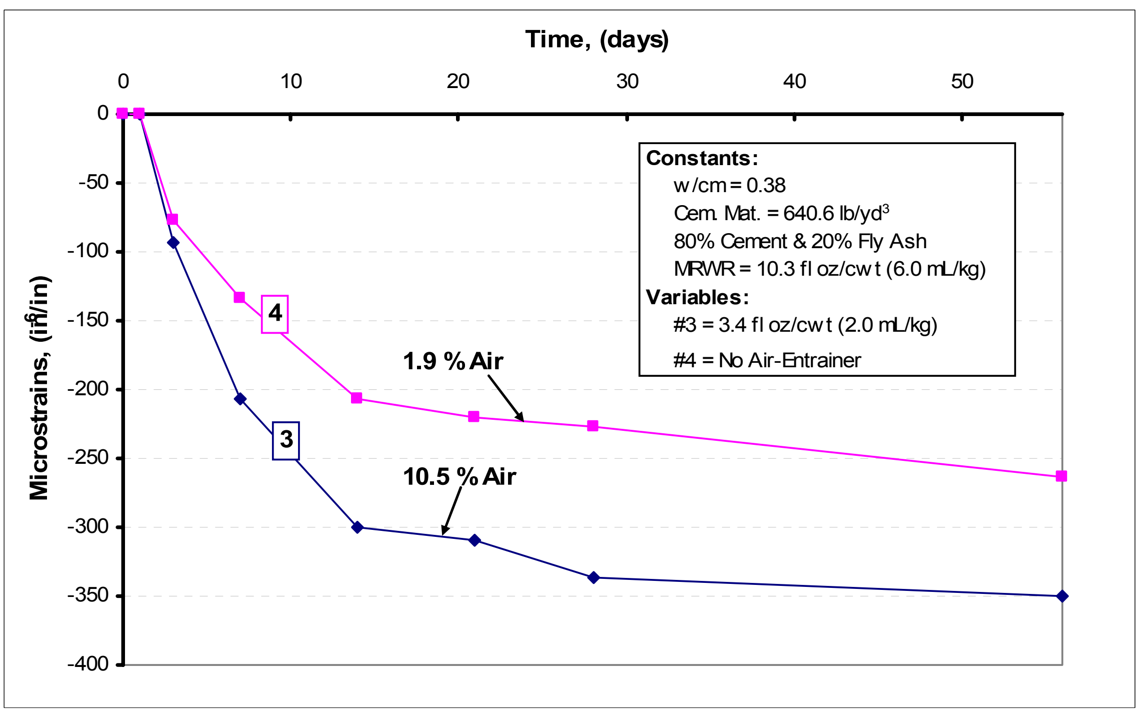


Figure 5. 2 – Unrestrained Length Change of Matrix 1 (Air-Entrainer)



5.2.2 Matrix 2 (Cementitious Materials Content)

In Matrix 2, many uncertainties existed concerning how the materials would all act together. As previously stated it was known through common concrete practice that the cementitious materials, or more accurately the Portland cement, develop most of the material cost and contribute to the volumetric change of the concrete. Thus this study went about trying to lower the total amount required.

Throughout this study, a trend was found in the levels of air produced. As the researchers lowered the cementitious materials content each time, the air contents were lowered as well. This is partially due to the dosage rate of the air-entrainer, 3.4 fl oz/cwt (2.0 mL/kg), is directly related to the total amount of cementitious materials. The air and cementitious materials contents for each batch in this matrix are as seen in Table 5.1.

Table 5. 1 – Matrix 2 Variables

Batch #	Air Content	Cement Content
	%	lb/yd^3 (kg/m^3)
3	10.5	640.6 (380)
5	13.5	607.0 (360)
6	7.2	573.2 (340)
7	6.4	539.5 (320)

It is noted that Batch 5 did increase in air content from Batch 3; however, this is believed to be a prime example of the air-entrainer variability. Since Batch 3 was batched at a different time, there were different environmental variables that may have affected this value such as increased air and concrete temperatures or the decreased relative humidity. None the less, the trend follows. Refer to Table 4.2 for the temperature and relative humidity data as well as the fresh and hardened concrete properties.

It is seen that the combination of the lower cementitious materials and air contents allowed the compressive strengths to increase and shrinkage affects to be reduced. However, it has not been clearly determined if these results are primarily due to the decrease in cementitious materials, the affects that have been seen in relation to the air contents, or a combination of both. Figures 5.3 and 5.4 display the compressive strength and unrestrained length change over a 56 day period for Matrix 2.

Figure 5. 3 – Compressive Strength of Matrix 2 (Cementitious Materials Content)

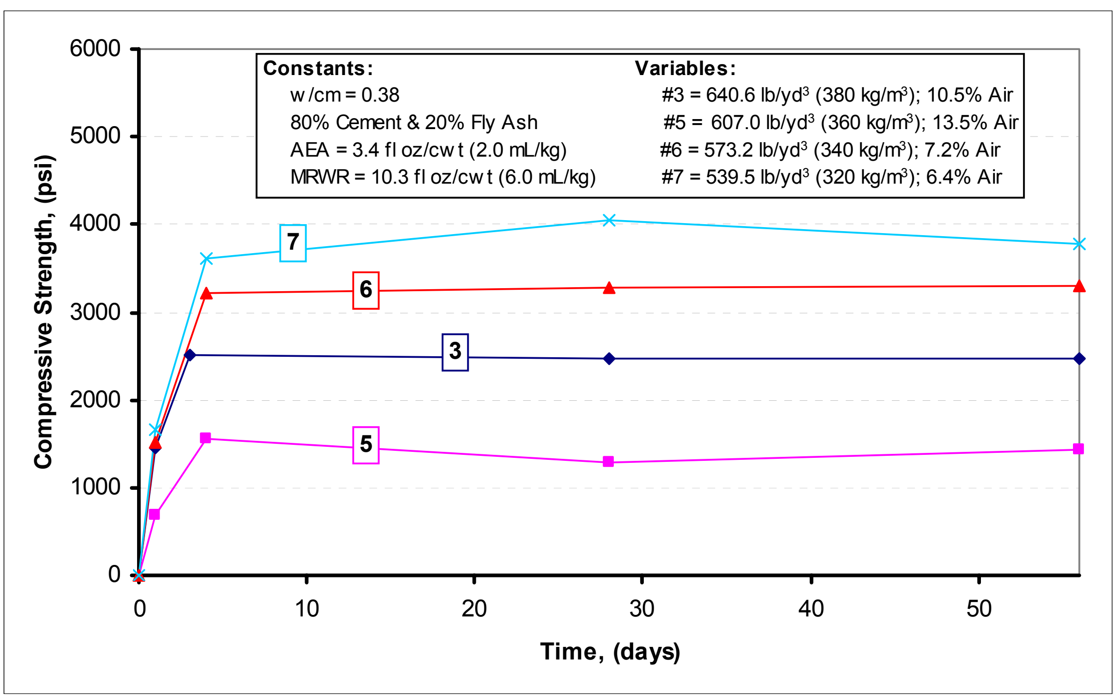
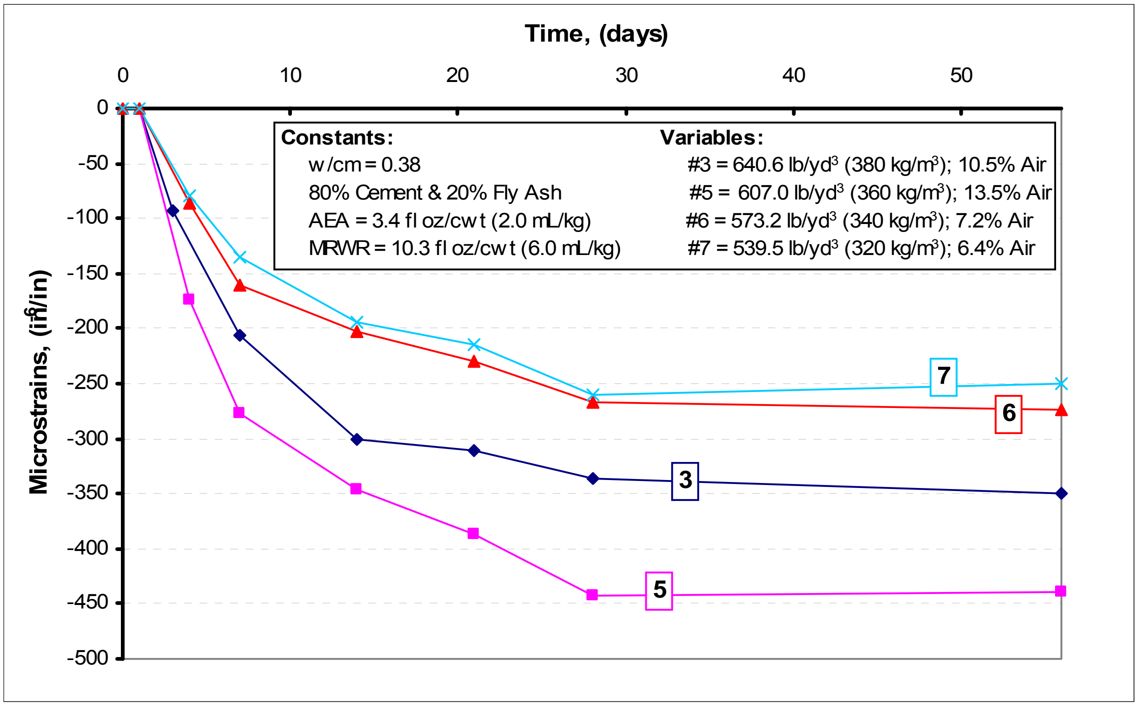


Figure 5. 4 – Unrestrained Length Change of Matrix 2 (Cementitious Materials Content)



Even with the reduction in shrinkage from decreased cementitious materials and air contents, the shrinkage results displayed a balancing point at the 573.2 lb/yd^3 (340 kg/m^3) content level. Thus, Batch 6 was chosen to continue the research from the air contents and hardened concrete properties achieved even though Batch 7 contained higher compressive strength results. Batch 7 was not chosen because it is believed that the increase in strength was not enough to over rule the air content and shrinkage data. It was determined that Batch 6 contained a cementitious materials and air content combination that produced results close to the design goals as well as produced length change results comparable to Batch 7. In choosing Batch 6, the recommendation by the Portland Cement Association of having a minimum cement content of 564 lb/yd^3 when severe freeze-thaw, deicer, and sulfate exposures are to be placed on the concrete (Kosmatka & Panarese, 1994) is fulfilled as well.

5.2.3 Matrix 3 (Aggregate Blend)

Finding the optimum aggregate blend is a large portion of this research. For all of the batches performed, the air contents were all approximately in the 7% range, with the exception of the high value of Batch 9 (11%) and the low values of Batches 10, 13, 14, and 15 (around 4-5%). Refer to Tables 4.4 and 4.5 for the fresh and hardened concrete values. These air contents produced were not expected. None the less, it can be seen in Figures 5.5 and 5.6 that each of these blends was still producing closely the same strength and shrinkage results. With the addition of the unintentional air content variability, it is hard to clearly see how the aggregate blends actually affected the concrete. Thus, no definite conclusions were made based off of the compressive strength and unrestrained length change results for the aggregate blends. This led to the investigators choosing the appropriate blend through the criteria of workability and the DRUW. The blend chosen, which is rationalized in the succeeding sections, in this research was Blend 21. Blend 21 consists of the following proportions:

- **#57 Coarse Aggregate 41%**
- **3/8" Chip Intermediate Aggregate 11%**
- **Sand 48%**

Figure 5. 5 – Compressive Strength of Matrix 3 (Aggregate Blend)

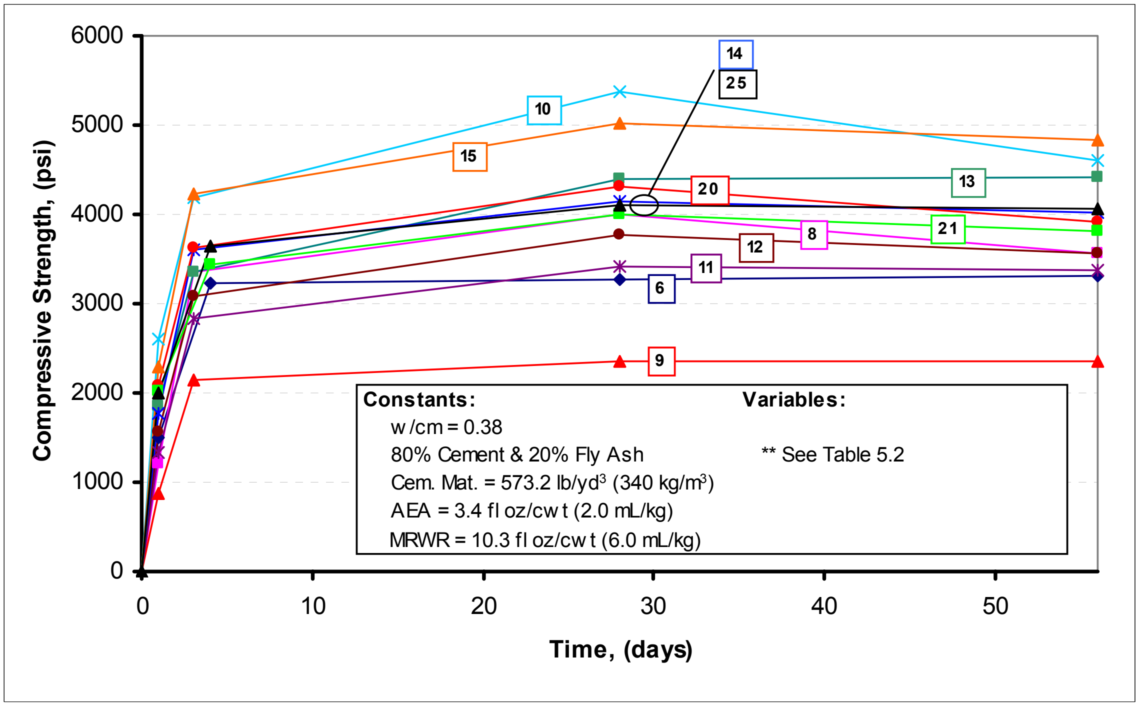


Figure 5. 6 – Unrestrained Length Change of Matrix 3 (Aggregate Blend)

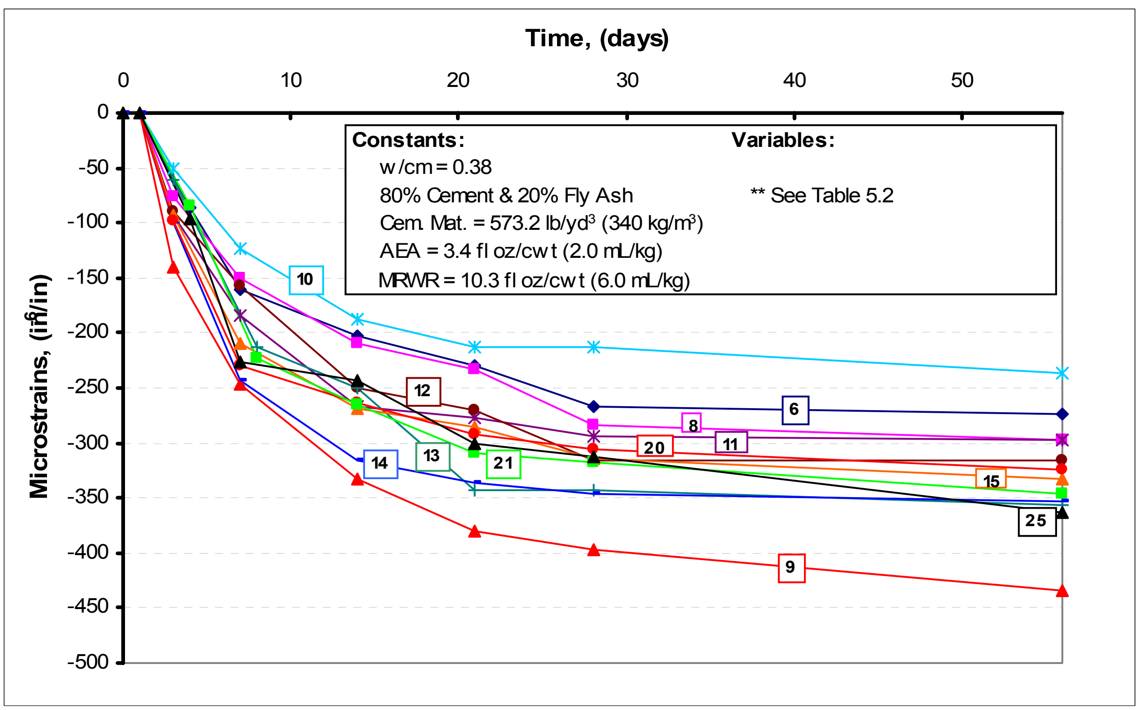


Table 5. 2 – Variables of Matrix 3 (Aggregate Blend)

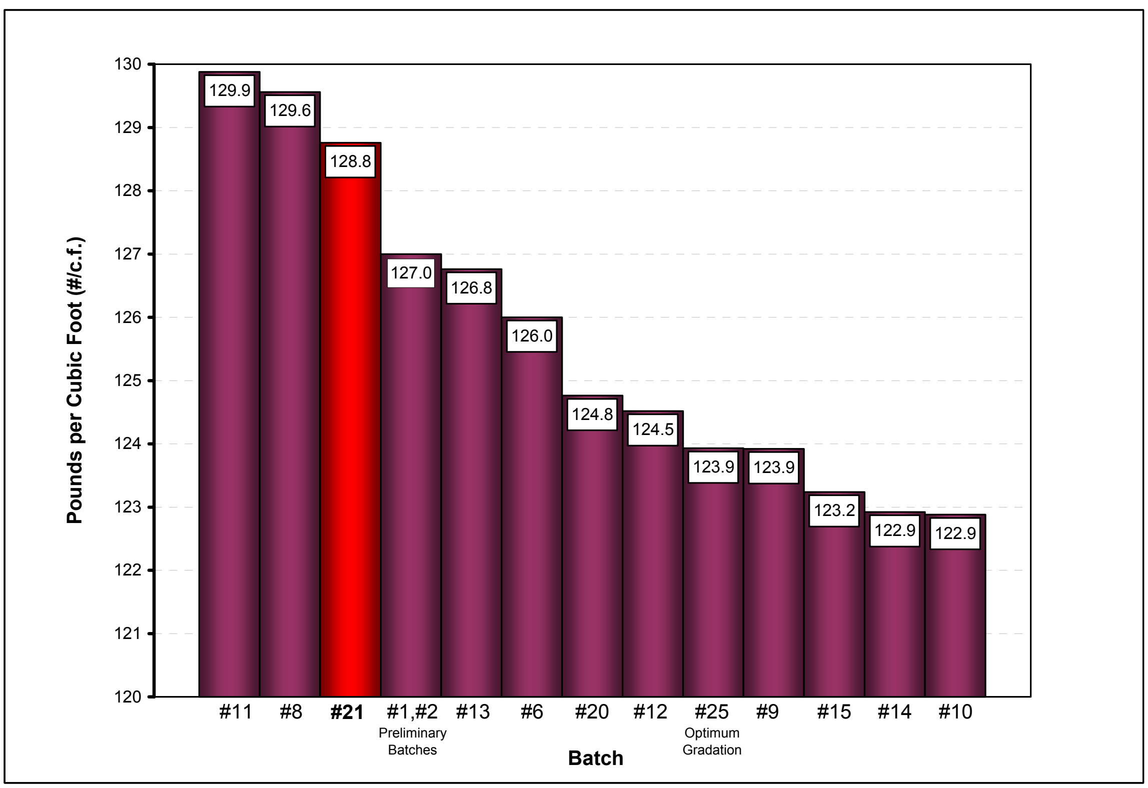
Batch #	Preliminary Batches				Air Contents
	Richardson Spur			Dover	
	Coarse		Intermediate	Fine	
	#57		N/A	sand	
1,2	57%		---	43%	9% - 14%
	Matrix 3 -- Aggregate Blends				**Air Contents**
	Cooperton			**Comargo**	
	Coarse		**Intermediate**	**Fine**	
	#57	**#2**	**3/8" chip**	**sand**	
6	37%	---	24%	39%	7.2%
8	35%	26%	---	39%	7.2%
9	25%	---	37%	38%	11.0%
10	43%	---	27%	30%	4.5%
11	20%	41%	---	39%	6.4%
12	15%	40%	---	45%	7.0%
13	35%	---	19%	46%	4.7%
14	26%	---	30%	44%	5.8%
15	32%	---	27%	41%	5.1%
20	15%	37%	---	48%	6.0%
21	41%	---	11%	48%	8.0%
25	Sieve sizes combined for optimum gradation				5.3%

5.2.3.1 Dry-Rodded Unit Weight (DRUW)

The DRUW allowed the researchers a chance to visually inspect the gradation of the blends and to produce quantitative results to gauge the density of the aggregates in each batch while attempting to minimize the void spaces. Surprisingly, Blend 21 (41%-#57, 11%-3/8" Chip, 48%-sand) with one of the highest DRUWs and one of the best workability characteristics during the batching process was chosen even though it goes against the results of the Shilstone Coarseness Factor chart.

Normally a high DRUW corresponds to a low workability due to an abundance of larger coarse limestone aggregates are used; however, Blend 21 reached a higher DRUW by incorporating the 3/8" chip intermediate limestone aggregate to fill the voids which adds smaller particles to increase the workability. In addition, Blend 21 has a higher proportion of sand than normal mixes which helped with this as well. It should be noted that adding an intermediate aggregate does not always aid the workability. If the majority of these particles are angular shaped aggregates then the workability may even be hindered. Figure 5.7 displays Blend 21 in red compared to the DRUW of the other blends in the research.

Figure 5. 7 – DRUW of Aggregate Blends



The blending of the #57 Cooperton limestone coarse aggregate and Camargo sand with the #2 Cooperton limestone coarse aggregate instead of the 3/8" chip Cooperton limestone intermediate aggregate had some significant differences. The #2 aggregate in Batches 8 and 11 were blended with a DRUW comparable and even higher than that of the 3/8" chip blends; however, these higher DRUW results are expected to have been caused by the use of less sand and the increase in the larger particles actually weighing more. The amount of sand is relevant since the limestone aggregate particles have a specific gravity of 2.67 versus the sand particles with a specific gravity of 2.63. This allowed the blends with more sand filling the voids to generally have a lower DRUW. This trend depends on whether the particle size distribution allows more sand to fill the voids.

5.2.3.2 Shilstone Coarseness Factor Chart

The suitability of using the Shilstone method of blending aggregates was a portion of our investigation. For this study the plot in Figure 5.8 was used to plot each blends corresponding Coarseness and Workability Factors. Refer to Table 5.3 for the factor results. In the Figure 5.8 Shilstone plot which was created by the primary investigator from previous Shilstone research, the diagonal zone between the black lines represents the Shilstone trend of the desired aggregate blends. The green circle narrows the desired blend region with the thick red line displaying the optimal region of the blends.

The Workability Factor is determined by the finer particles. This means the farther up the y-axis the blend is found the more sandy the mixture and vice versa. In turn, the blends above the top diagonal trend line are classified as sandy and below the bottom trend line are classified as rocky. As for the Coarseness Factor, this is determined by the larger particles. Thus, the farther left on the x-axis a blend is found the larger the particle sizes of the large aggregates. This explains the #2 coarse limestone aggregate blends, 8 and 11, discussed in the previous section having a rocky finish.

Figure 5. 8 – Shilstone Target Zone

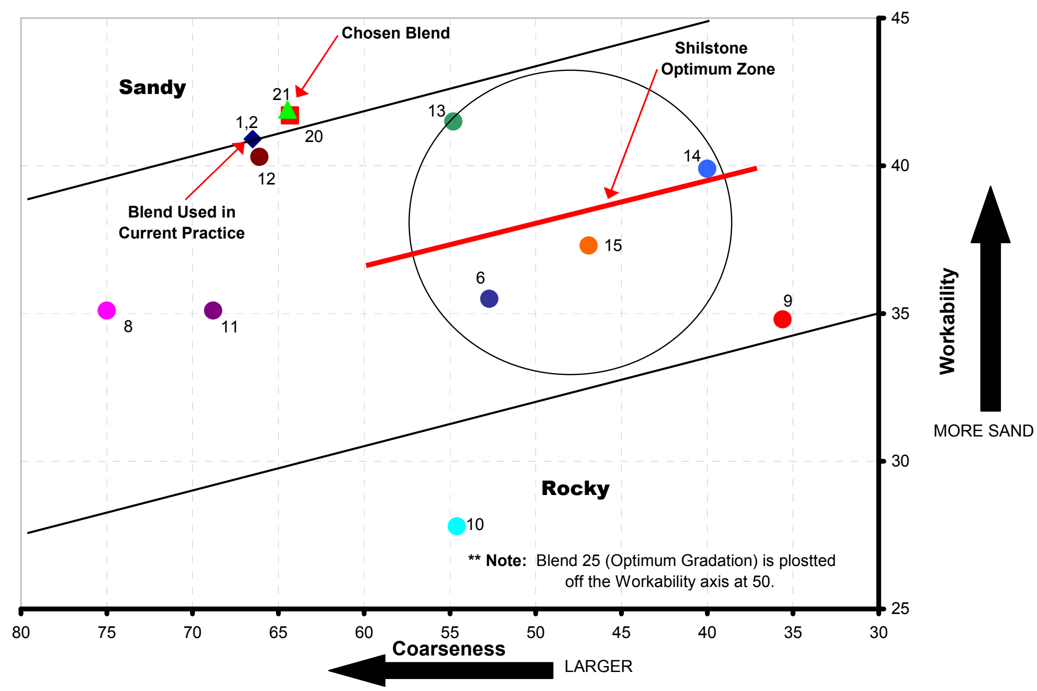


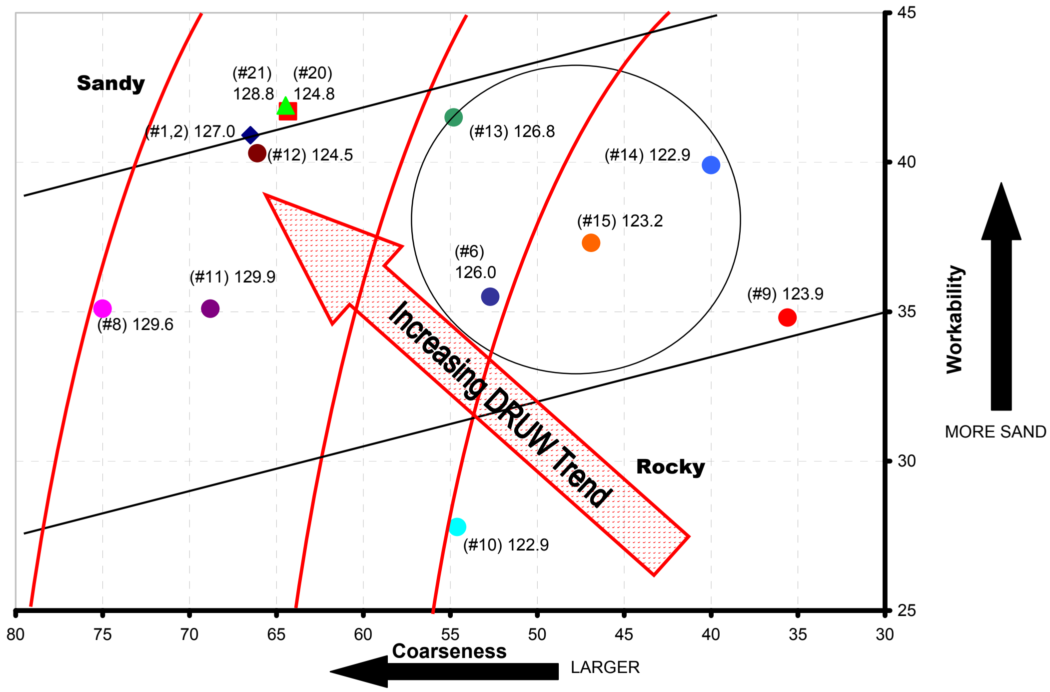
Table 5. 3 – Shilstone Coarseness and Workability Factors for the Aggregate Blends

	Batch #											
	1,2	8	9	10	11	12	13	14	15	20	21	25
Coarseness	65.5	73.8	35.0	54.0	67.8	64.8	53.8	39.2	46.2	64.3	64.5	42.0
Workability	43.0	34.1	33.9	27.0	34.1	39.2	40.3	38.8	36.2	41.7	41.9	50.0

The blend that was used in the research up to Matrix 3 was Blend 6. This blend was chosen by the primary investigator due to its positioning on the Shilstone Coarseness Factor chart presents it as a possible optimum blend. However, Blend 21 just into the sandy region was chosen. Another fact that should be pointed out is that of the location of the Preliminary Batches Blend, Blends 1 and 2. The Preliminary Blend was created using the two aggregate commonly seen in construction practice today. The fact that Blend 21 is in the same region aided in choosing it since the current construction practice has deemed this region suitable for workability in Oklahoma. Blends 12 and 20 in the same region were produced using the #2 coarse aggregate and not the 3/8" chip intermediate aggregate. Blend 20 was actually designed to have approximately the same Shilstone factors as Blend 21. However, due to the DRUW and workability characteristics that are present in the blends containing the #2 coarse aggregate, the blends were less than optimal and were comparable in workability to the Preliminary Batches.

Figure 5.9 displays the DRUW values for each of these blends plotted on the Shilstone Target Zone. It can easily be seen that a trend of increasing DRUW values is found as the blends move up in both the Workability and Coarseness Factors. The anomalies, Blends 12 and 20, are explained through the use of the #2 coarse aggregate with an increased amount of sand. The red arcs plotted further show that this increasing pattern tends to have a sweeping action; however, the actual trend regions can not be defined with the available data at this time. The high DRUW values inside the trend lines, Blends 8 and 11, can be explained with the use of the #2 aggregates having a high DRUW.

Figure 5. 9 – DRUW Plotted on the Shilstone Target Zone



In this investigation the Shilstone Coarseness Factor chart has created some concern with its validity. Such a concern is found in the trend areas provided by Shilstone's research. These trend areas are nice guides in judging the aggregate blend; however, the aggregate blends actually created do not always produce these characteristics. This could be partially due in this research to the multiple variables produced through the combinations of admixtures used. In Shilstone's studies he used certain admixtures in characterizing his mixtures. In reality though, not all concretes are created with exactly the same constituent ingredients where each of these materials affect the performance of the concrete in different ways. These variables make it hard to create an exact trend area for all concrete use. Thus, trial batching and experience with given materials is necessary to accurately create performance trend areas. Shilstone does have considerable research to back his findings using certain constituent materials. However, the study with the materials he had available provides reinforcing data that the overall concept is well thought, but local materials should still be analyzed to find their given performance.

Shilstone provides observations of physical evidence of aggregate blends with adequate intermediate and other particle distributions in concretes structures from the past. He states that if structures over 50 years old (now 60 years), which are still in service, are examined after the surface is abraded, there will be many intermediate particles exposed. In contrast, modern mixtures can be seen with a great deal of ½ inch (12.5 mm) particles and little else between that size and the mortar (Shilstone, 1990). Figure 5.10 and 5.11 display the ASTM C 33 gradation curves for a blend from 1923 and 1988, respectively. It can easily be seen that a more adequate blend is provided in the 1923 ASTM C 33 specification. This request from Shilstone that a concretes aggregate content contain the appropriate amount of intermediate particles to fill the voids is also seen in the blend that was chosen in this research; however, as stated earlier, the chosen blend does not contain the amounts of each size suggested by Shilstone.

Figure 5. 10 – Combined Gradation (1923 ASTM C 33), **(Shilstone, 1990)**

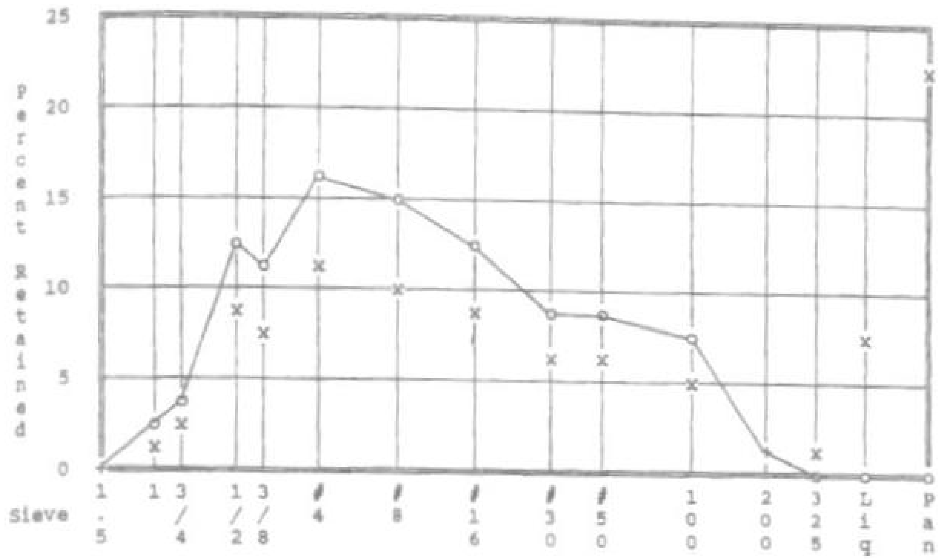
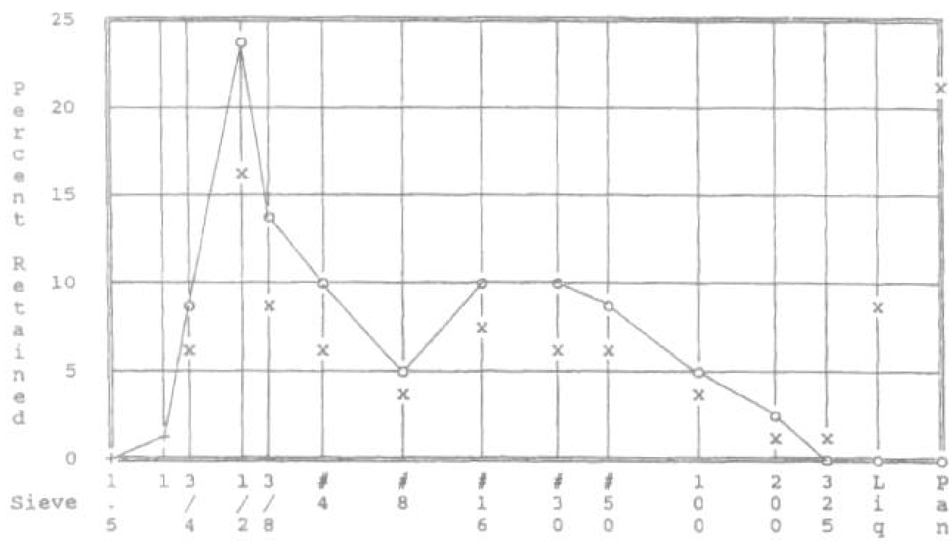


Figure 5. 11 – Near Gap Graded Mixture (1988 ASTM C 33), **(Shilstone, 1990)**



It is difficult to develop an adequate conclusion by the investigators of the Shilstone method's performance with the data obtained in this investigation. This is due to the additional variable of the air contents in the concretes creating further changes to the mixtures. Overall, the results achieved in the Shilstone study lead to the belief that the Shilstone method is not accurate or at least not easily followed. The chosen blend in this investigation being located near the currently used blend leads to the belief that the bulk density method of aggregate blending commonly used may more easily produce a desirable blend. However, it is still recommended to use an intermediate aggregate in the blend to achieve fewer voids in the concrete.

5.2.3.3 Percent Retained

In addition to the Coarseness and Workability Factors, the Shilstone method states that some method of analyzing the particle size distribution in the mix should be used. There are several methods mentioned for this including a modified 0.45 power chart, the 8-18 rule, or the percent retained. However, since the percent retained was mentioned predominantly by Shilstone and was deemed to be the best way to visually see the gradation by the researchers, the percent retained charts were used in this investigation.

Problems have been found in concrete practices of the past with gap grading. In general, intermediate particle sizes are found to be missing from the blend including sizes such as #8 (2.36 mm), #16 (1.18 mm), and #30 (0.600 mm) and an excess of fine materials retained on the #50 (0.300 mm) and #100 (0.150 mm) sieves. This lack of intermediate sizes and abundance of smaller particles can lead to construction and serviceability problems as well as a high water demand.

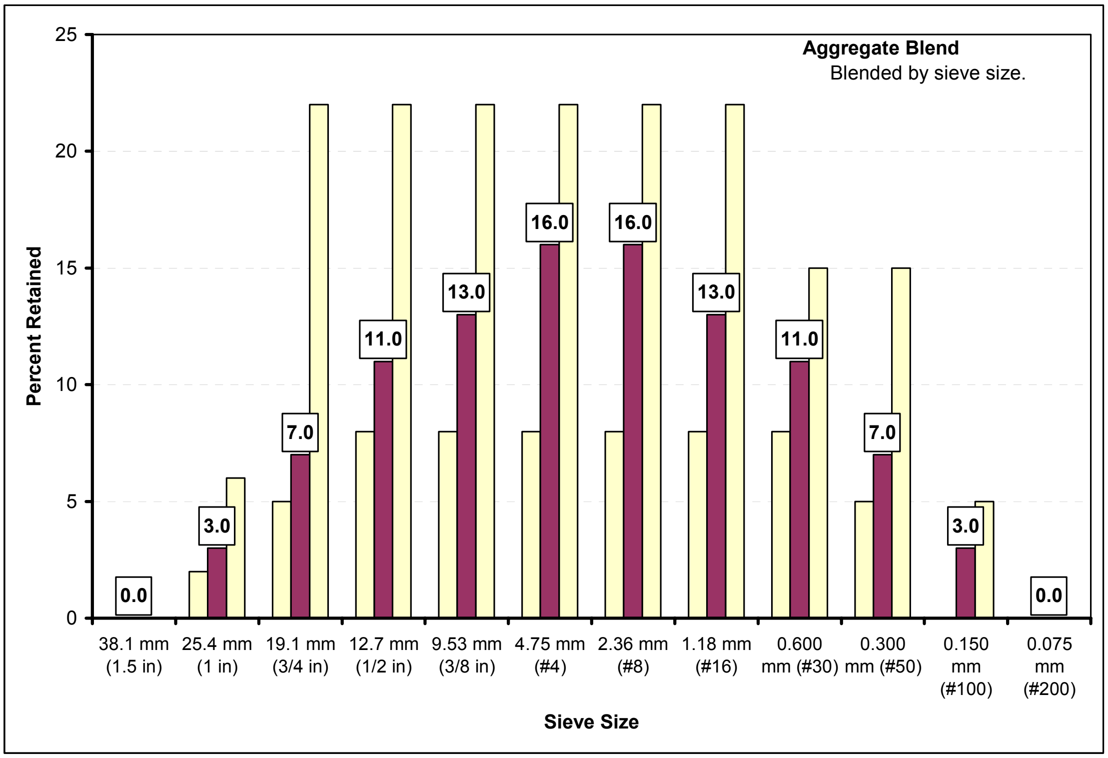
As a result, the concrete performance can be improved by using a uniformly graded aggregate (ACI 211-A, 2004).

For this research, specifications were provided on the range requirements for the amount retained on each sieve. The gradation blends were manipulated by the researchers in order to find a blend that would satisfy these requirements. However, it was found that with the materials for use it was impossible to achieve the guidelines set for each sieve. A lack of 3/8”, #8, and #30 materials as well as an abundance of the #50 were the most common difficulties found. This gapping of particle sizes is a common occurrence in concrete practice due to the variations in gradation from different aggregate sources and the common practice of selling these sizes to the asphalt industry. However, ACI Committee 211-A states that a deficiency in one particle size of aggregate may not cause a problem as long as there is a sufficient amount of materials just smaller or larger.

An additional study on the optimum blend was performed as a reference. During the sieving process, each sieve size was stored separately and then combined to produce a blend, 25, with the optimum percent retained. When this blend was used in batching, no noticeable increase in strength, workability, or decrease in shrinkage was found (see Figures 5.5 and 5.6). However, once again it is difficult to accurately judge the true affects of the blend due to the air content variability produced. In addition, the corresponding Shilstone plot for the blend was off of the target zone chart used due a large workability factor produced.

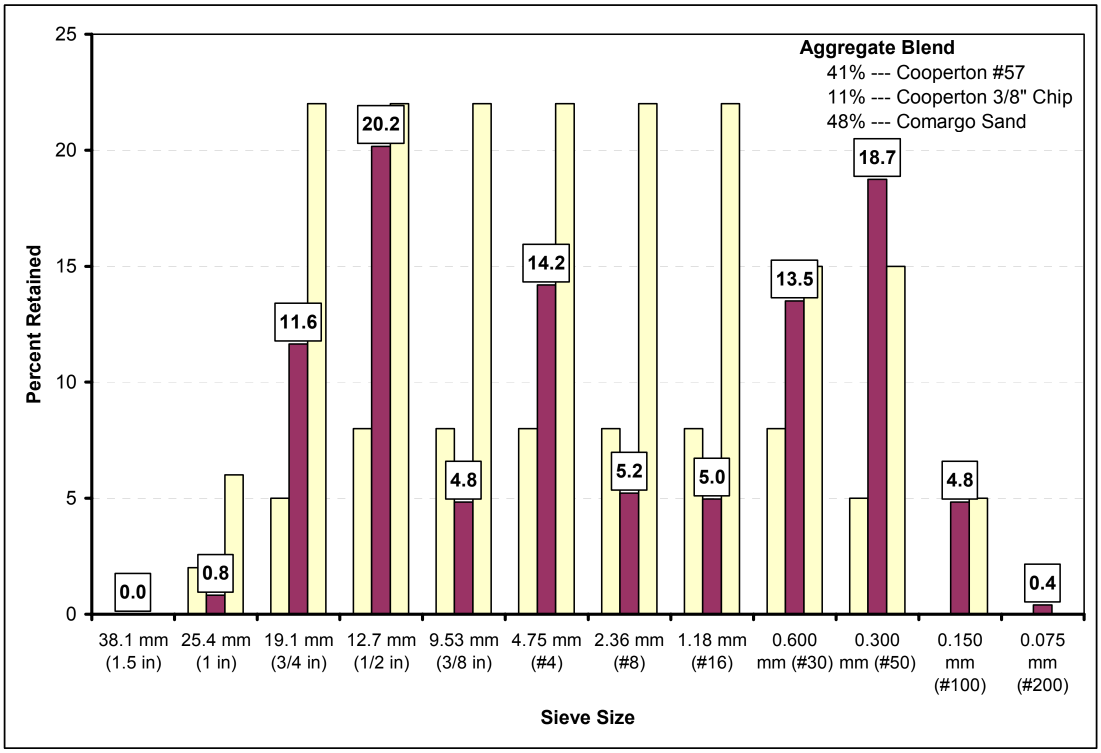
Figure 5.12 presents the percent retained for the optimum blend where the cream bars represent the sieve high and low criteria and the crimson bars represent the blend.

Figure 5. 12 – Percent Retained for the Optimum Blend (Blend 25)



With all of the retained results found, it was decided by the researchers to focus the blend choice more closely on the Shilstone method. However, as seen in Figure 5.13, the chosen Blend 21 was quite efficient on the percent retained comparable to the fore mentioned optimum blend. This was due to abundance in the particle sizes next to the particle sizes that were lacking.

Figure 5. 13 – Percent Retained for the Chosen Blend (Blend 21)



5.2.4 Matrix 4 (w/cm)

Matrix 4 was set up to study the w/cm affects on the mixtures. Up to this point a w/cm of 0.38 was in use which was determined by the primary investigator. HPC mixtures are usually characteristic of using the lowest w/cm possible; however, it was reasoned appropriate not to decrease the value for this investigation any lower than 0.38. The reason for this was for constructability. The construction site being designed for is approximately a twenty minute drive for the concrete trucks. Thus, it was a concern to lower the ratio and create a dry mixture at the site. According to the Portland Cement Association, concrete which will be exposed to the presence of deicing chemicals should have a maximum w/cm of 0.45 and for air-entrained concrete to achieve a compressive strength of 4000 psi should be 0.48. Thus with these guidelines, the increased w/cm ratios in the study of 0.40 and 0.42 are still considered low.

The results achieved in this study showed that the compressive strength decreased and a larger presence of shrinkage was obtained as the w/cm was increased. Figures 5.14 and 5.15 display the compressive strength and unrestrained length change results over a 56 day period for Matrix 4. However, the air-entrainer seemed to directly react with an increase in the water content. This creates difficulty in determining between the effects the water content and the variable air contents produced have on the concrete characteristics. None the less, the trends seen, with the issue of travel time of the concrete, led the researchers to choose a w/cm of 0.38. The corresponding air contents were as follows:

- **Batch 15 (0.38) = 5.1%**
- **Batch 16 (0.40) = 9.3%**
- **Batch 17 (0.42) = 11.5%**

Figure 5. 14 – Compressive Strength of Matrix 4 (w/cm)

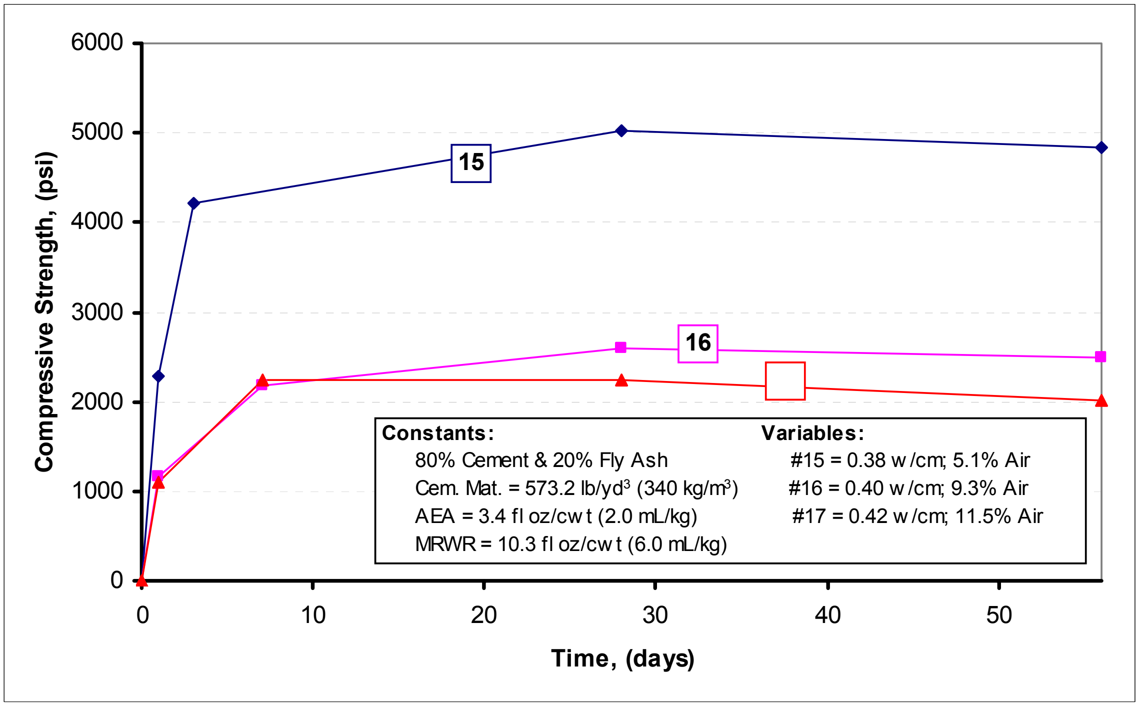
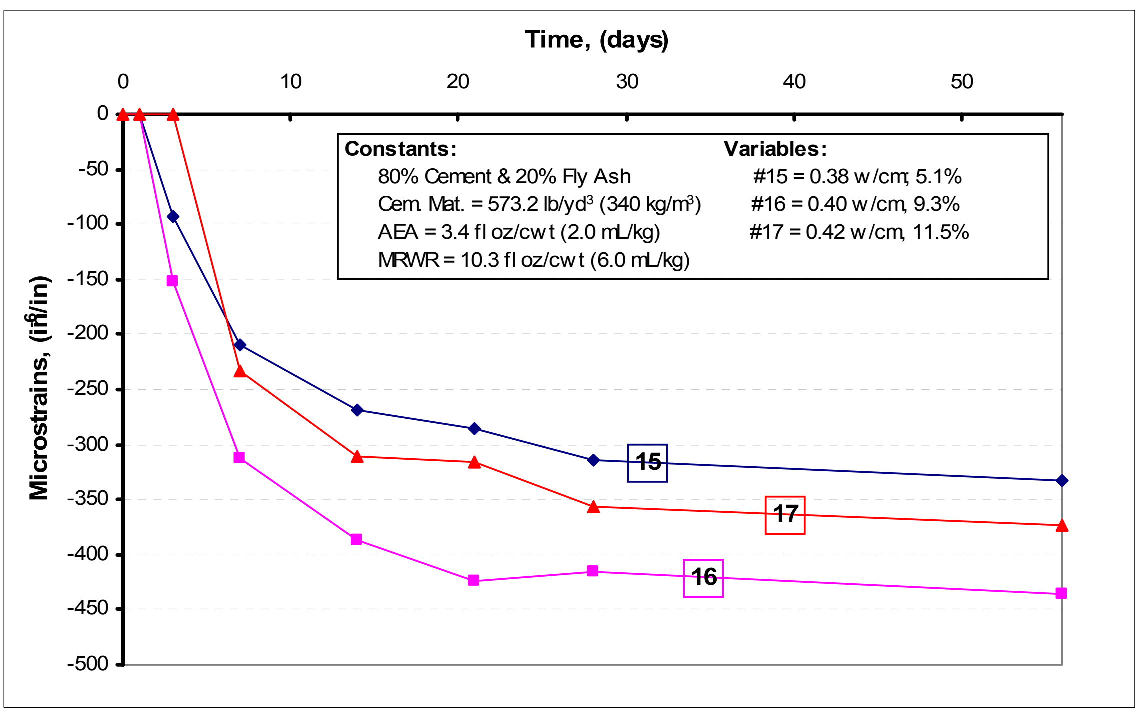


Figure 5. 15 – Unrestrained Length Change of Matrix 4 (w/cm)



5.2.5 Matrix 5 (Supplemental Cementitious Materials)

The combination of slag and fly ash with Portland cement was the focus of Matrix 5. The proportioning of 20% fly ash and 80% cement was used in all the batches up to this point. This division was decided by the primary investigator due to common practice and maximum fly ash substitution rates set by ODOT.

For this research two batches were performed with only 50% cement: one with 50% slag, Batch 18, and the other with 30% slag and 20% fly ash, Batch 19. An additional batch, Batch 22, with 100% cement was performed for comparative purposes. The compressive strength and unrestrained length change results over a 56 day period are provided in Figures 5.16 and 5.17, respectively.
The compressive strength and shrinkage results produced from this study are hard to interpret due to the variable air contents produced. It is unclear of any trends or of what variables varied the air contents. None the less, Batch 18 with 50% slag produced a low shrinkage result even for a low air content mixture. Additionally, Batch 19 with the fly ash and slag blend had an air content of 9.75% but was still at the same shrinkage readings as Batch 22 with the 100% cement containing a 6% air content. Refer to Table 4.12 for the fresh and hardened concrete properties.

Figure 5. 16 – Compressive Strength of Matrix 5 (Supplemental Cementitious Materials)

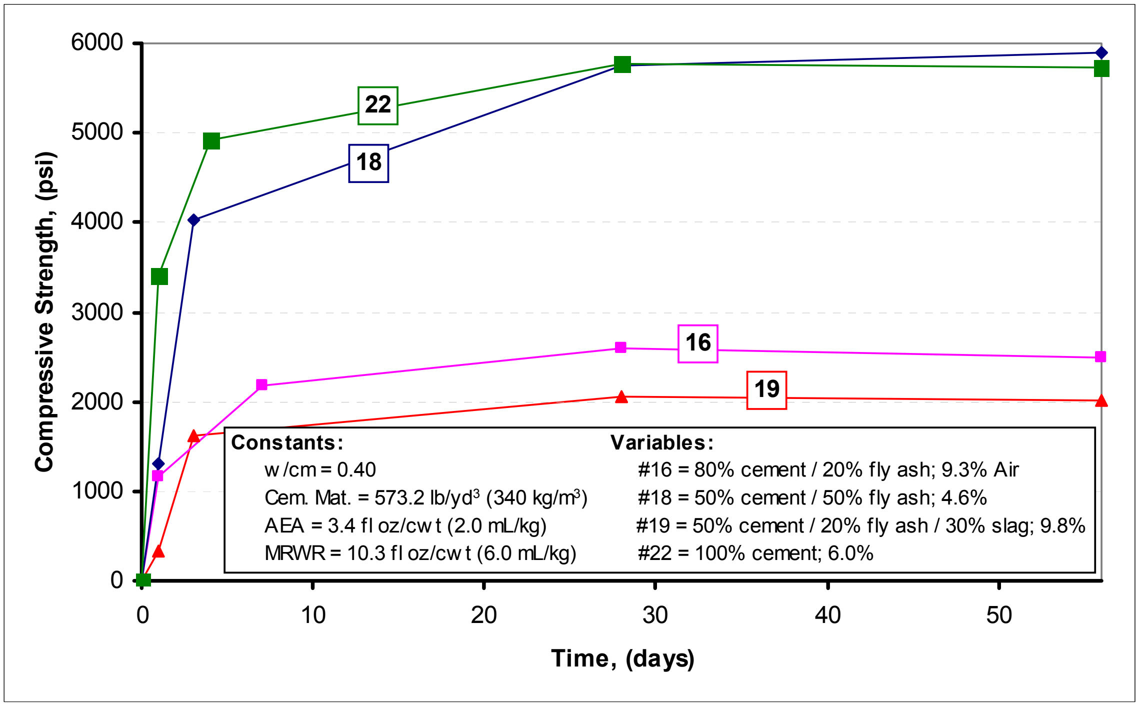
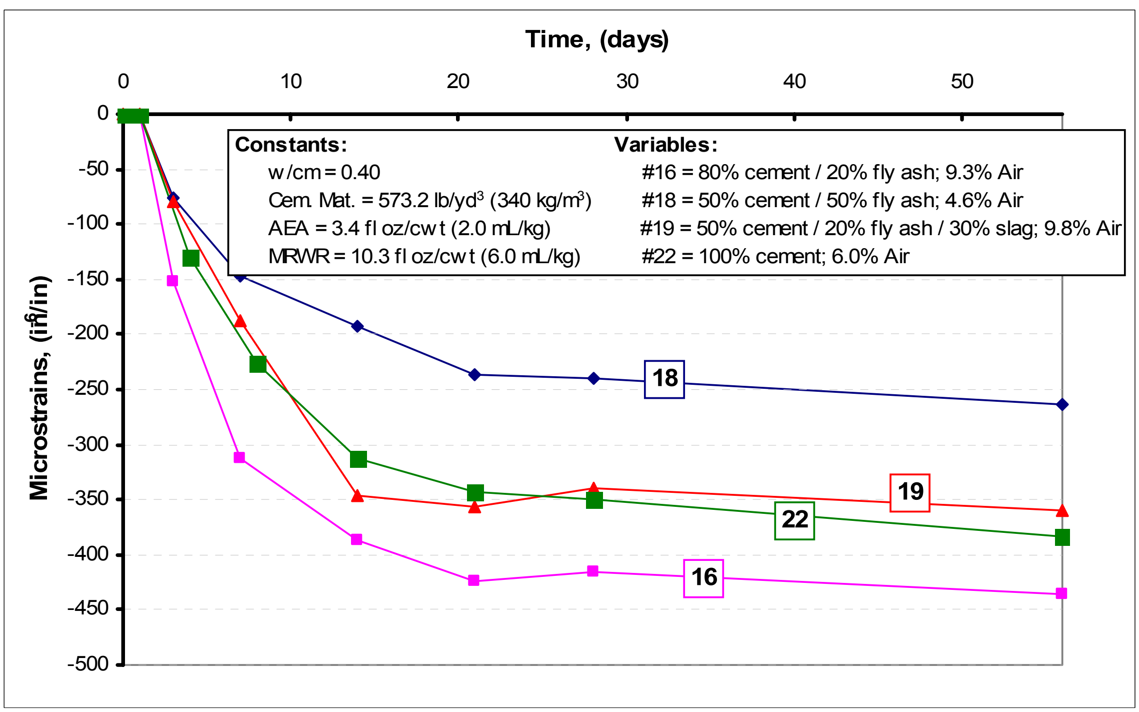


Figure 5. 17—Unrestrained Length Change of Matrix 5 (Supplemental Cementitious Materials)



The results found from the slag batches were promising. However, the researchers decided to use fly ash in the continuation of the research due to the availability of the materials since the mixtures being designed were to be created with local materials. Even though the slag was provided from a local batch plant, it was produced near Chicago, Illinois. As a result, the 20% fly ash and 80% cement blend was selected to continue the investigation.

5.2.6 Matrix 6 (Fibers)

The initial scope of work requires that two of the four final HPC mixtures produced will include fiber reinforcement. From a parallel investigation performed at Donald G. Fears Structural Laboratory, the fiber type and dosage rate were determined for this research. This consists of Fibermesh ½" Stealth Fibers at a dosage rate of 5.1 lb/yd^3 (3.0 kg/m^3). Matrix 6 was setup to simply view the affects that the fibers will have on the mixtures. The addition of fibers was seen to be hopeful for the scope of this investigation in decreasing the shrinkage and overall service life of the concrete. It has been seen in past research that fiber reinforced mixtures tend to improve crack control (Ramseyer, 1999).

It was found that the fibers lowered the air content found in the mixture approximately 2.5%. This data is important; however, it is difficult to compare the compressive strength and length change results due to the unintended air content variable. It is predicted with the other batches with out fibers that this difference in air would follow the air content trend and produce approximately the same results if the two batches were brought to the same air content. However, fiber reinforced concrete acts as a completely different material compared to normal concrete. Through experience and discussion with other researchers it is predicted with the same air content the fiber mixture will perform comparable in strength and better in length change. Figures 5.18 and 5.19 present the compressive strength and unrestrained length change for Matrix 6, respectively.

Additional observations were made on the characteristics of the fiber mix during the compressive testing. The fiber mixture tended to fail in a ductile manner with out any of the characteristic fractures found in the other concretes. In addition, after the first sign of failure, they would stop taking load and then accept an additional loading amount before the ultimate failure. This characteristic adds to the possibilities of fibers. The ductile breaks may provide a more flexible concrete that can carry on additional loading after cracking and increased durability.

Figure 5. 18 – Compressive Strength of Matrix 6 (Fibers)

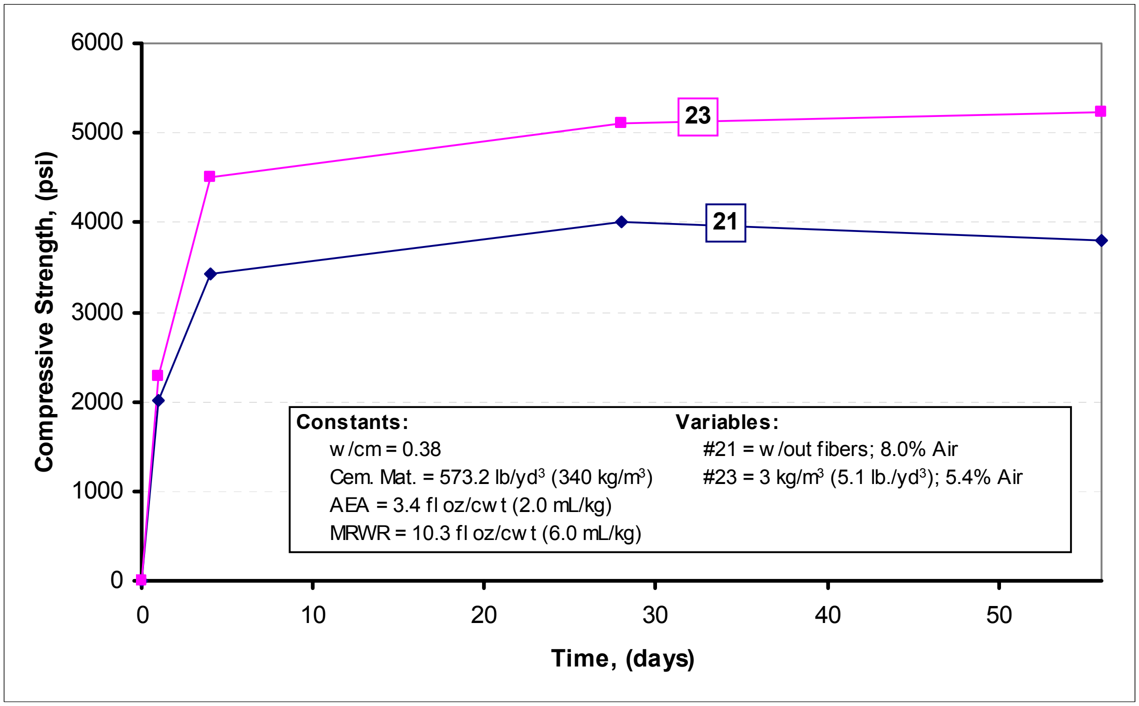
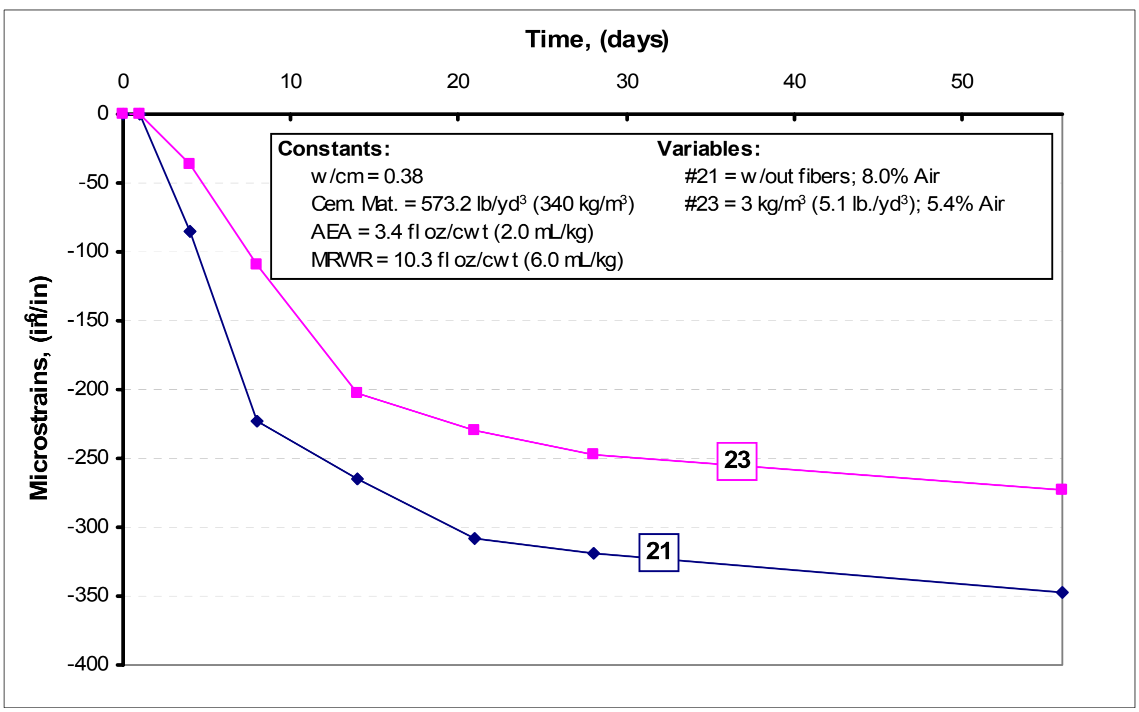


Figure 5. 19 – Unrestrained Length Change of Matrix 6 (Fibers)



5.2.7 Matrix 7 (Shrinkage-Reducing Admixture)

Matrix 7 was developed to view the affect of the shrinkage-reducing admixture Tetraguard® AS20 on the HPC. Figures 5.20 and 5.21 present the compressive strength and unrestrained length change results for this study. It was found that the compressive strength of the batch, 24, with the admixture was nearly doubled and the shrinkage results were lowered tremendously. The shrinkage data did not even break a hundred microstrains until 7 days after batching. It is believed that the trends found in this study are directly related to the air contents produced. Batch 24 had 3.3% air compared to the batch without the admixture, 21, with 8% air. In conclusion, the Tetraguard® helps shrinkage issues without adversely affecting the compressive strength, but these characteristics are due to the lowering of the air content which is still in need of being more fully understood. Additionally, the Tetraguard® was found to increase the workability to some affect.

Figure 5. 20 – Compressive Strength of Matrix 7 (Shrinkage-Reducing Admixture)

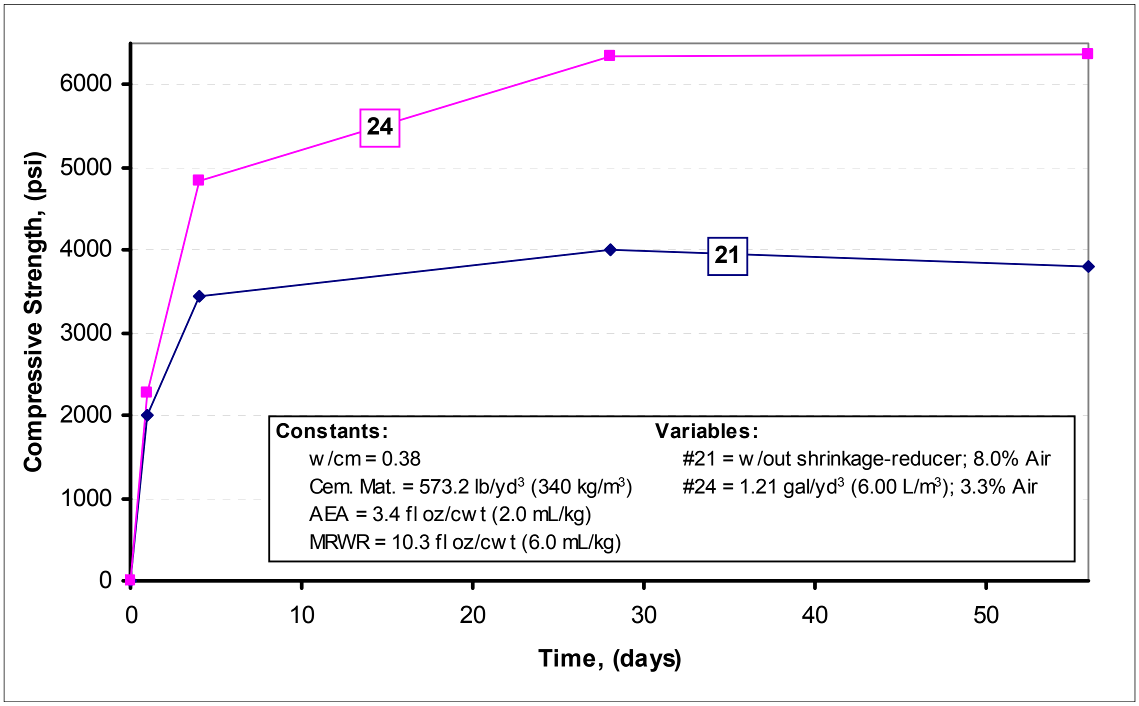
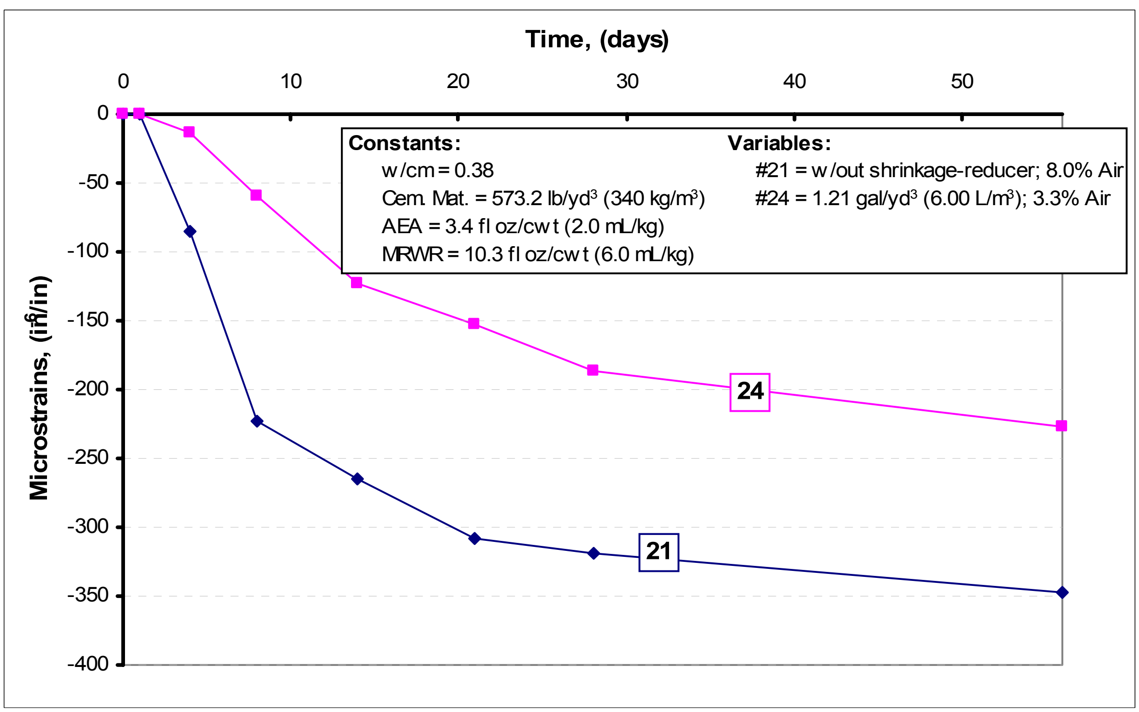
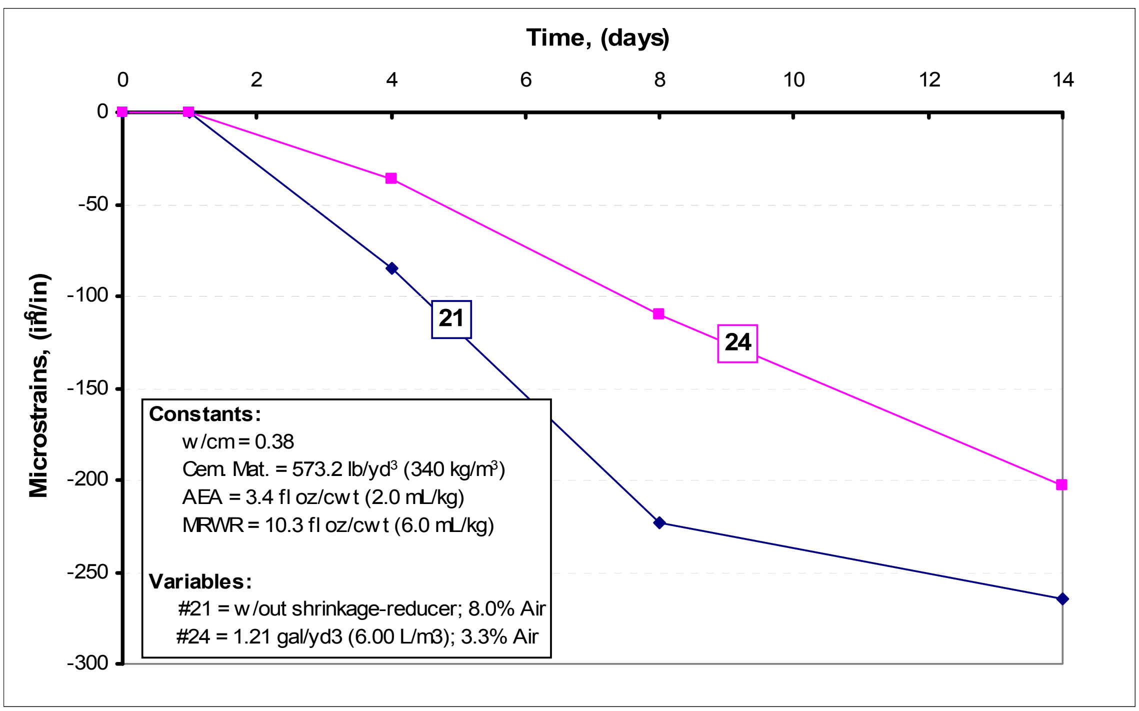


Figure 5. 21 – Unrestrained Length Change of Matrix 7 (Shrinkage-Reducing Admixture)



The decreased air content in the Tetraguard® mixture was to be expected due to the characteristics of the shrinkage-reducer. Tetraguard® decreases the stresses within the meniscus of the air bubbles produced in the concrete during the early stages of the mixture. This explains the extreme reduction in length change seen at an early age and the shrinkage trend that follows the batch without Tetraguard® starting after the14 day period. Figure 5.22 displays the unrestrained length change during the early curing stages.

Figure 5. 22 –Unrestrained Length Change of Matrix 7 (Shrinkage-Reducing Admixture) 0 thru 14 Day



The researchers realized the potential that Tetraguard® possesses in the outcome of a quality HPC mixture. Since the Tetraguard® seems to “kill” the air bubbles, it was realized that the possibility of altering the dosage rate of the shrinkage-reducer or increasing the initial air content could produce a mixture with exceptional shrinkage results and the air content desired. This was further studied in the secondary batches.

5.3 Secondary Batches

5.3.1 6% Designed Air Group

This group of batches simply displays the affects of a reduced concrete temperature. When the ice was added to Batch 27, which was in all other ways identical to Batch 26, the air content jumped from 5% to 11% air. This change was expected since temperature is a method of controlling air contents. The increased air content also produced expected results of lower compressive strengths and an increase in shrinkage. Figures 5.23 and 5.24 display the compressive strength and unrestrained length change results, respectively.

To balance the air content results from temperature, the air-entrainer dosage rate was cut in half for Batch 28. This change produced better shrinkage as well as higher compressive strength results than the batch without ice. However, even with the knowledge gained on the capabilities of temperature to control the air content, some adaptations were still found to be needed for the compressive strength since the results never reached the 4000 psi level.

Figure 5. 23 – Compressive Strength of the 6% Designed Air Group

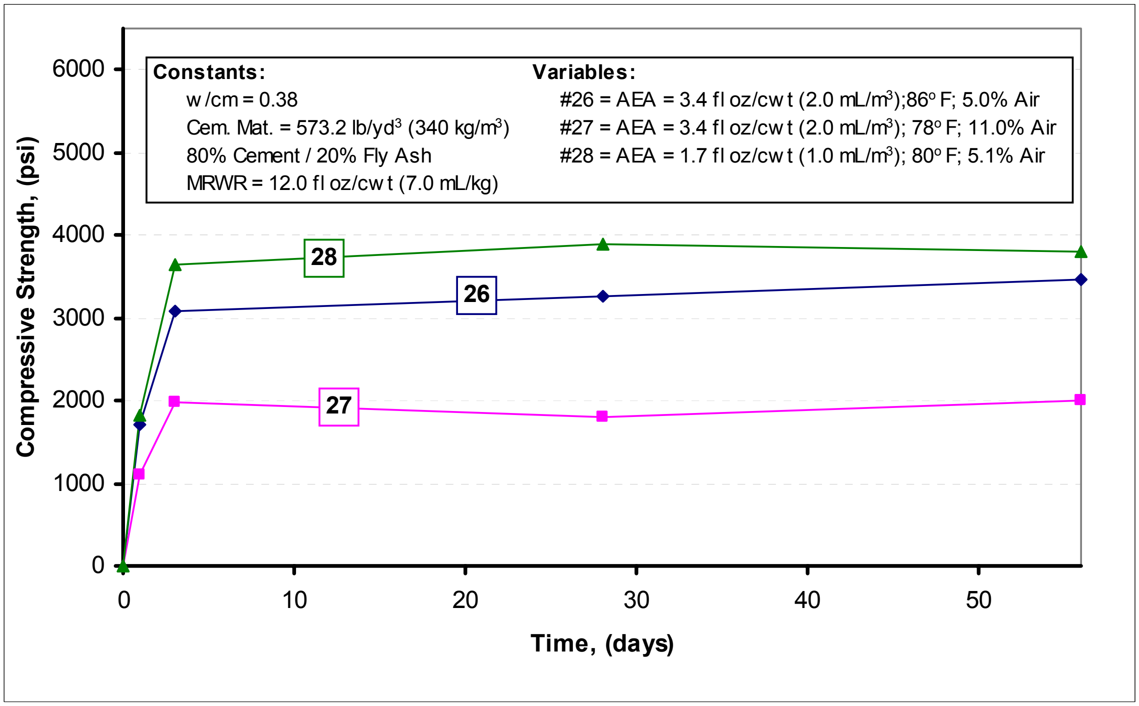
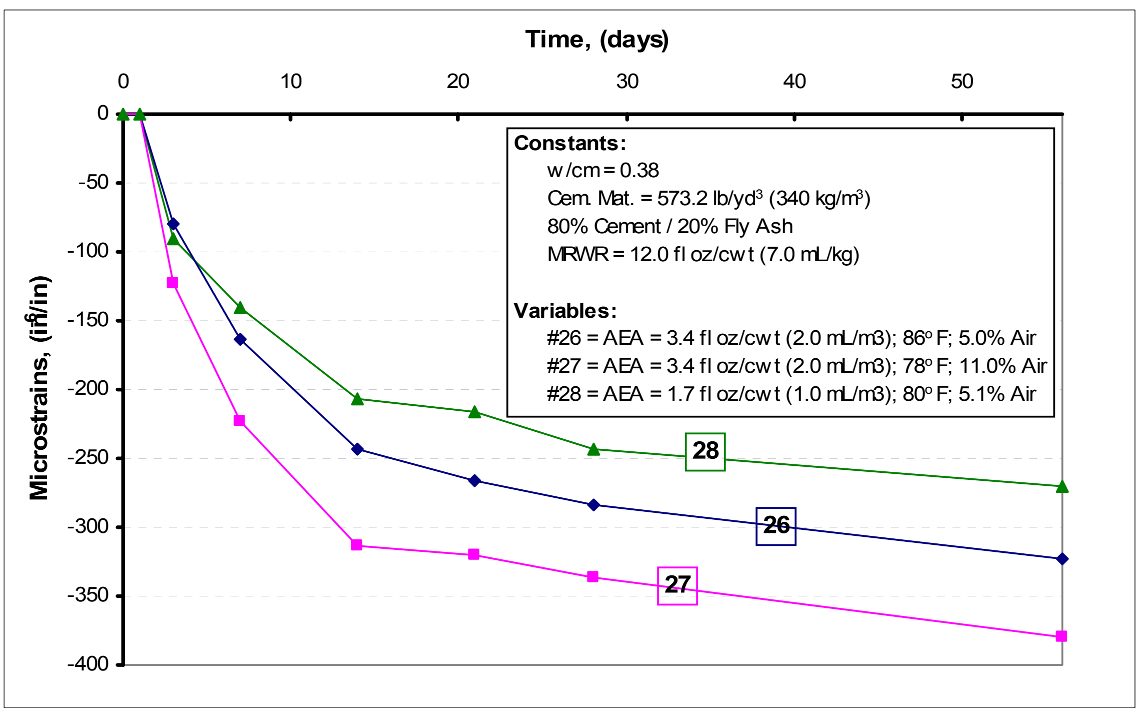


Figure 5. 24 – Unrestrained Length Change of the 6% Air Group



5.3.2 6% Designed Air Group with Shrinkage-Reducer

After viewing the results of the 6% Designed Air Group, the addition of Tetraguard® was made with modifications to the air-entrainer and mid-range water-reducer dosages to alter air and workability levels. It can be seen in Figures 5.25 and 5.26 that the compressive strength and shrinkage results were approximately the same for all of the batches due to the air contents achieved. The air content values for all the batches were found to be approximately 3% just as in Matrix 7. This is due to the air "killing" phenomenon associated with the Tetraguard® which was discussed in Section 5.2.7.

Due to the air depleting affects of Tetraguard®, Batch 32 was performed with the addition of the shrinkage-reducer at the end of the cycle and air-entrainer at the beginning with the aggregates in hope of letting the air bubbles fully form prior to the Tetraguard® addition. As can be seen in the graphs, the dosage rate of the Tetraguard® depleted the air content despite of this action and created approximately the same compressive and shrinkage results. However, it was still believed at this time that if the right amount of air-entrainer and shrinkage-reducer are added together that an acceptable HPC mixture can be produced.

Figure 5. 25 – Compressive Strength of the 6% Designed Air Group with Shrinkage-Reducer

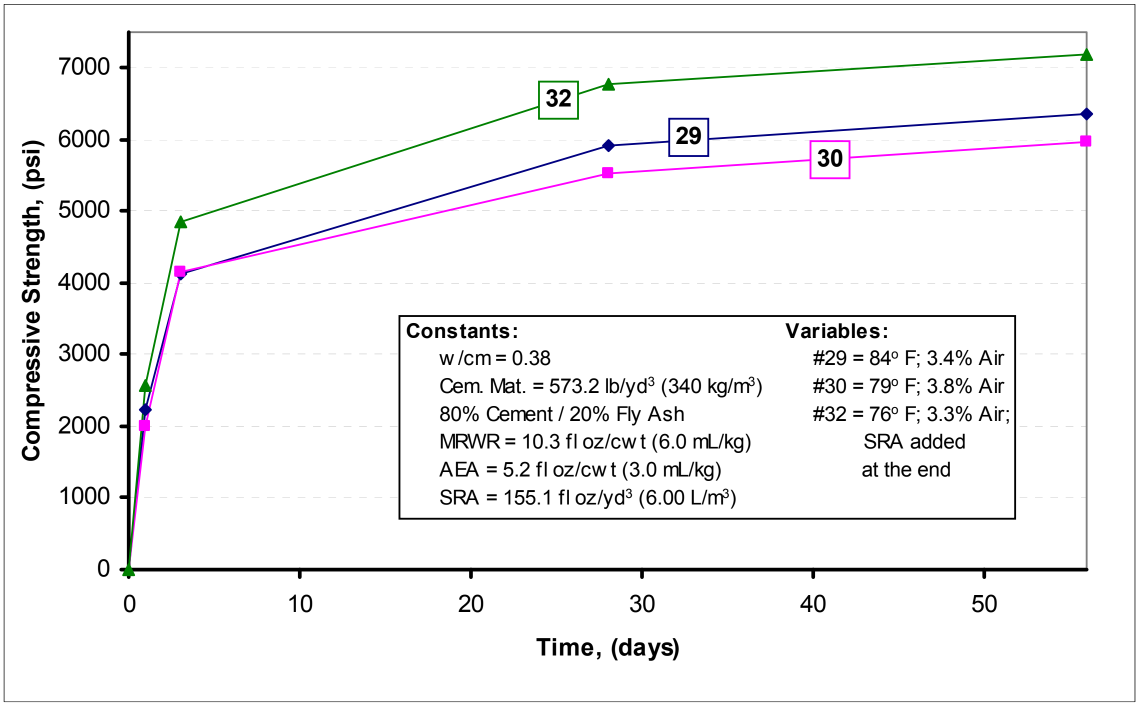
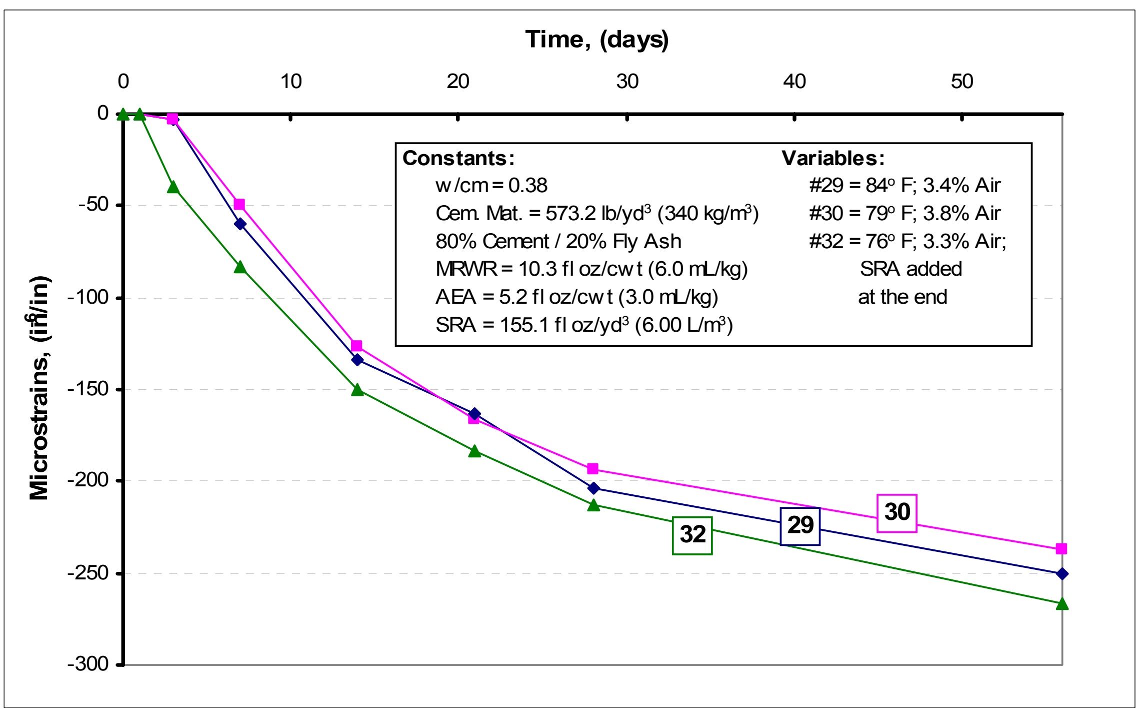


Figure 5. 26 – Unrestrained Length Change of the 6% Designed Air Group with Shrinkage-Reducer



5.2.3 8% Designed Air Group

Throughout the numerous alterations made in admixture dosages and the timing of there additions throughout this study, it was determined that the timing of the addition of the Tetraguard® was irrelevant to the batch results. It can be seen in Figures 5.27 and 5.28 that Batch 37 with an air content of 9% had the least desirable strength and shrinkage results where the rest of the batches with air contents ranging from 3% to 5% performed much better. The anomaly of the performance of Batch 34 with 3% air is not understood at this point. Since the air content explains the trend for the compressive strength and shrinkage results, a dosage rate that would achieve the air content specifications became the main concern.

Figure 5. 27 – Compressive Strength of the 8% Designed Air Group

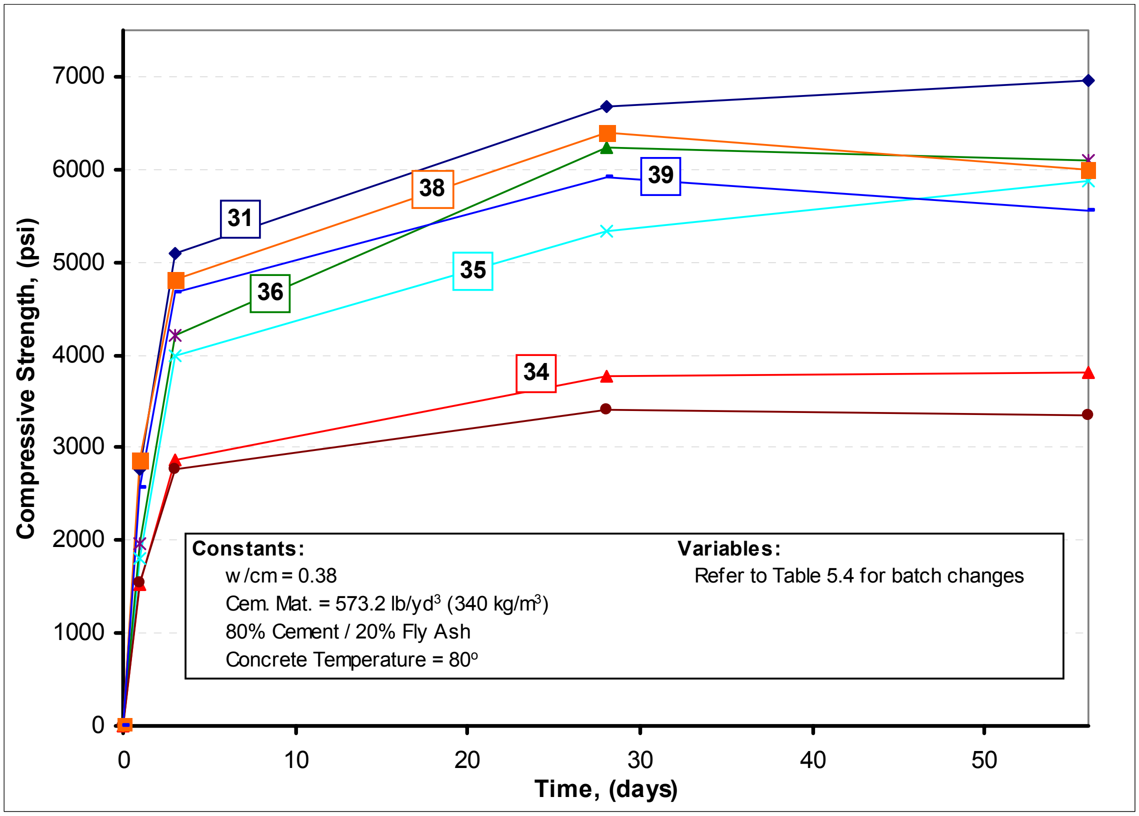


Figure 5. 28 – Unrestrained Length Change of the 8% Designed Air Group

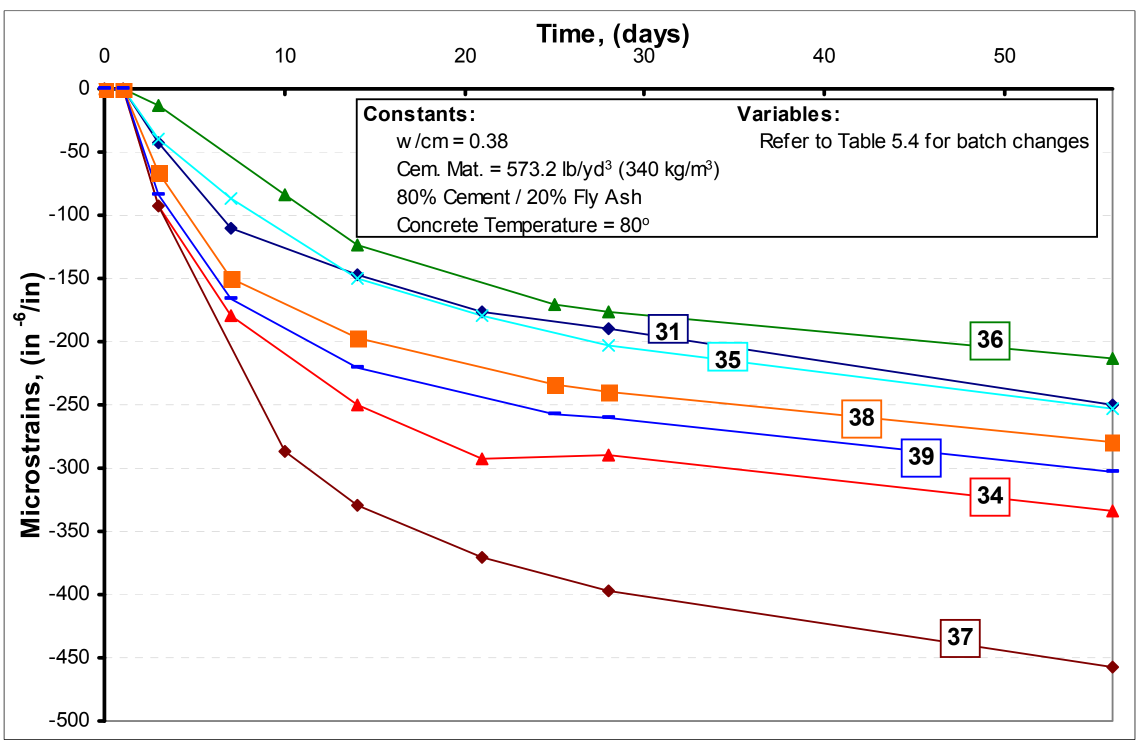


Table 5. 4 – Variables of the 8% Designed Air Group

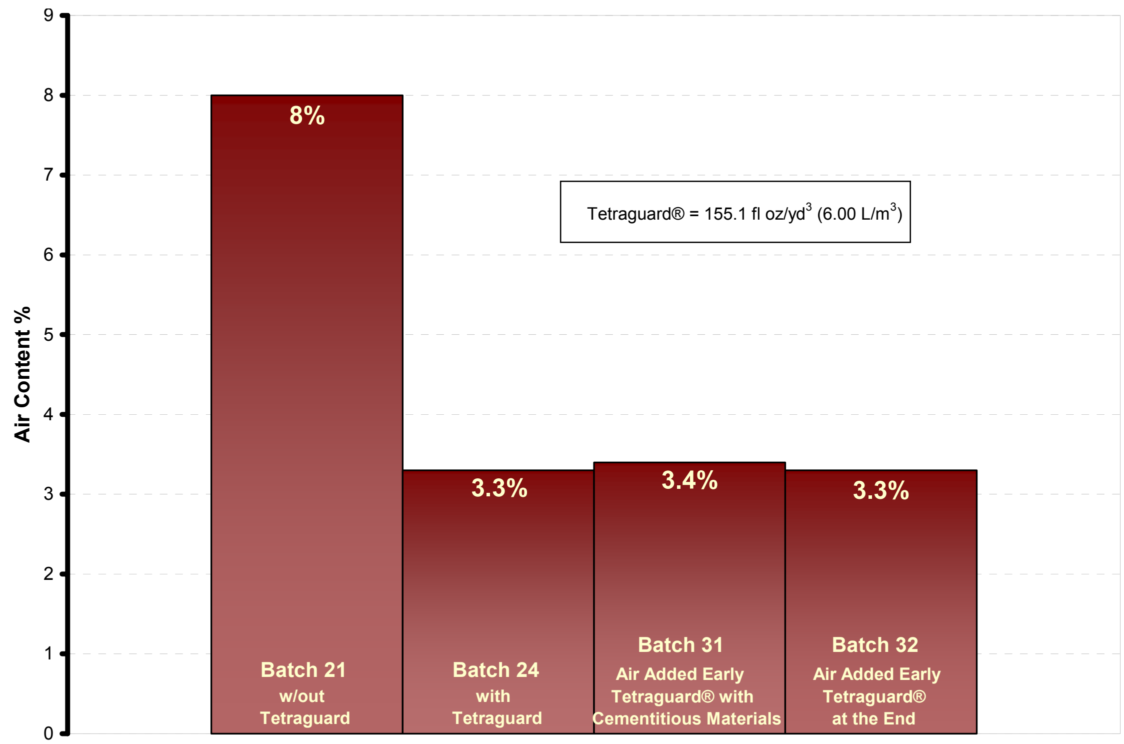
Batch #	(AEA) Air-Entrainer (MB AE™90)	(MRWR) Mid-Range Water- Reducer (Polyheed® 1020)	(SRA) Shrinkage-Reducer (Tetraguard® AS20)
	fl oz/yd^3 (mL/m^3)	gal/yd^3 (L/m3)	fl oz/yd^3 (L/m^3)
31	26.4 (1,020.0)	52.7 (2,040.0)	155.1 (6.00)
34	26.4 (1,020.0)	52.7 (2,040.0)	51.7 (2.00)
35	26.4 (1,020.0)	52.7 (2,040.0)	155.1 (6.00)
36	26.4 (1,020.0)	52.7 (2,040.0)	155.1 (6.00)
37	35.2 (1,360.0)	52.7 (2,040.0)	12.9 (0.50)
38	44.2 (1,710.0)	52.7 (2,040.0)	3.9 (0.15)
39	52.7 (2,040.0)	61.5 (2,380.0)	3.9 (0.15)

Batch #	Desiged Air Content	Actual Air Content	Admixture Addition Method
	%	%	
31	8.0	3.0	AEA (with Aggregates) SRA (with Cem. Mat.)
34	8.0	3.0	AEA (with Aggregates) SRA (at the end of mixing)
35	8.0	4.0	AEA (with Aggregates) SRA (at the end of mixing with the 5 min / 1 min cycle)
36	15.0	3.0	AEA (with Aggregates) SRA (at the end of mixing with the 5 min / 1 min cycle)
37	8.0	9.0	AEA (with Aggregates) SRA (at the end of mixing with the 5 min / 1 min cycle)
38	8.0	5.0	AEA (with Aggregates) SRA (at the end of mixing with the 5 min / 1 min cycle)
39	8.0	5.0	AEA (with Aggregates) SRA (at the end of mixing with the 5 min / 1 min cycle)

Figure 5.29 displays the affects of the timing of the Tetraguard® addition through batches in this group and earlier. It can be seen that when the Tetraguard was added normally or when the air-entrainer was added early with the aggregates to agitate the air bubbles in addition to the Tetraguard® at different times, the air content produced each time was comparable with the approximately 3% seen.

This Tetraguard® trend led to Batch 37 being chosen due to its dosage rate did not bring the air down in this drastic manner. It should be noted that the lowest dosage rate batches, 38 and 39, were not chosen for two reasons. The first was due to workability. These batches were both very dry. This is believed to be associated with the quality control issue of a high moisture content found in the sand used in these batches creating a water content in mixing that was not true to design, but also to the increased workability from the shrinkage-reducer may have possibly been lost from the lower dosage. Secondly, Batch 37 was close to the compressive strength goal for the investigation. The larger dosage of Tetraguard® for Batch 37 was chosen over 38 and 39 since a higher quantity of Tetraguard® used can only help the shrinkage and does not have an adverse affect on the compressive strength.

Figure 5. 29 – Effects of the Timing of theTetraguard® Addition

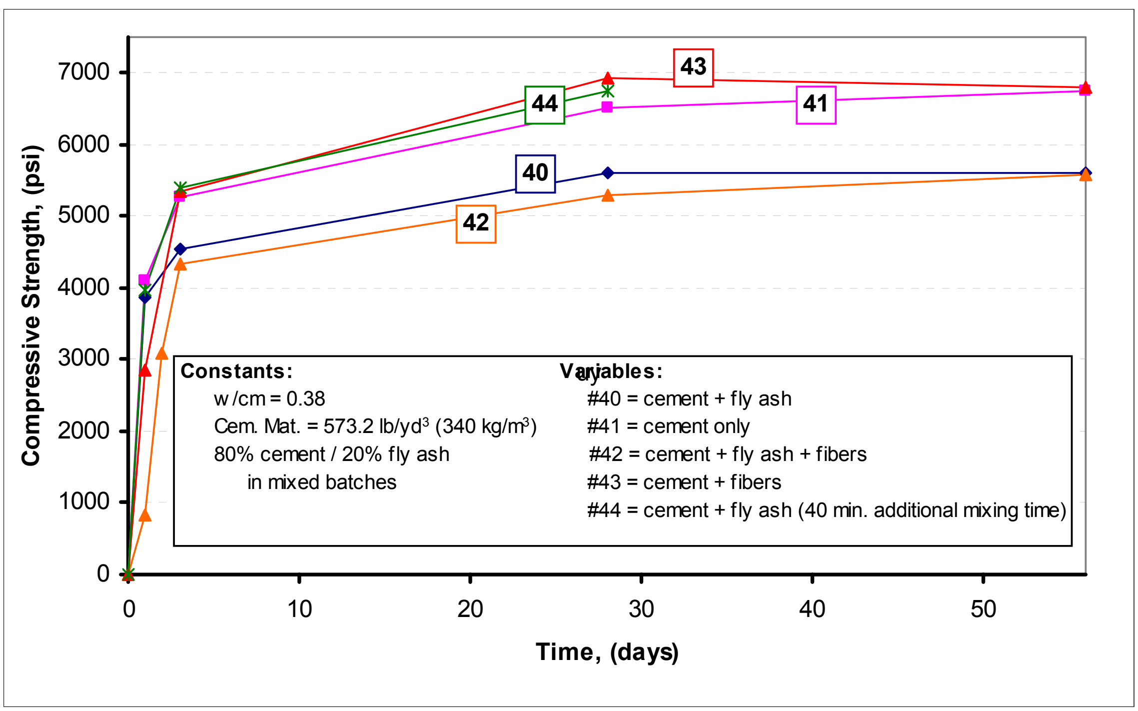


5.4 Final Batches

The final batches produced in this section developed a mix design for four different HPC mixtures with two including fiber reinforcement as set out at the beginning of the investigation. Each of these batches developed the necessary criteria set by ODOT such as air content, slump, compressive strength, and low shrinkage.

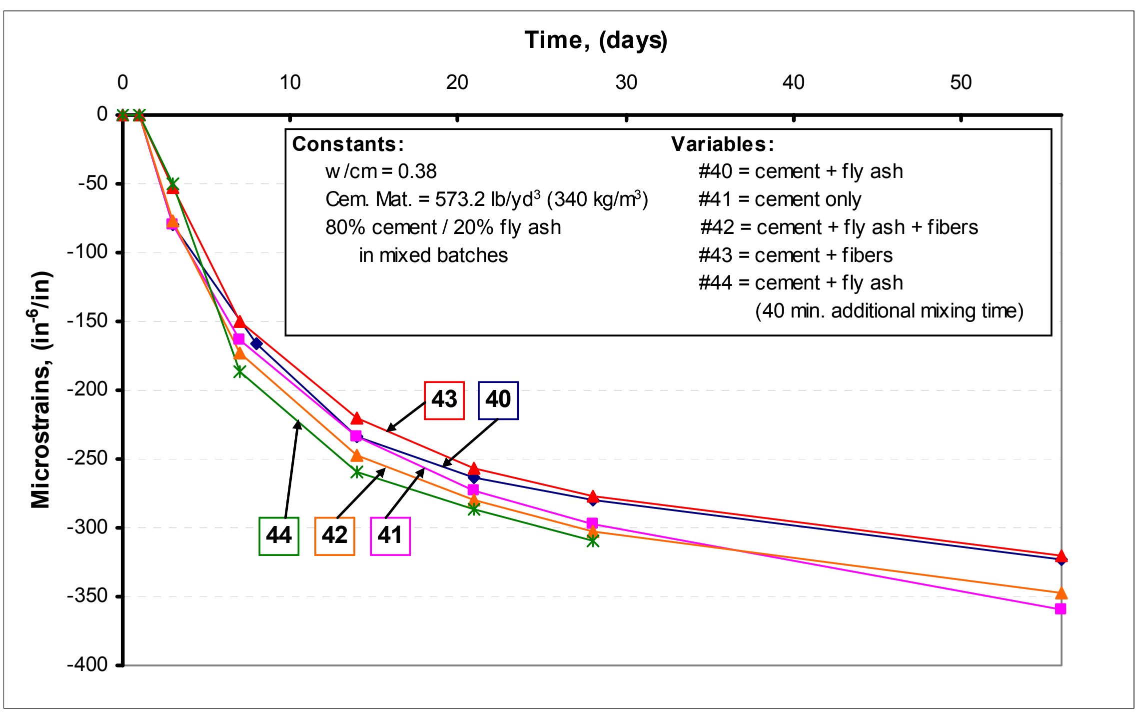
As can be seen in Figure 5.30, each of the batches developed the necessary 4000 psi compressive strength. As was expected, the batches with cement only performed better in compression than those with the fly ash blend due to there characteristic properties. This was shown in the Matrix 5 study as well. None the less, the fly ash batches, 40 and 42, were still above standards with compressive strengths over 5000 psi. Batch 43, cement + fibers, developed a slightly larger strength than that of Batch 43 with only cement. This is understandable due to the increase in strength the fibers provide due to their nature of accepting additional loading after first failure. On the other hand, the fly ash batch with fibers, 42, performed with a little less strength than Batch 40 with cement and fly ash only. Overall, these two observations display that the addition of the fibers did not alter the strength performance of the mixtures in a positive or negative way. The slight difference in value, whether higher or lower, was not much of significance.

Figure 5. 30 – Compressive Strength of the Final Batches



The unrestrained length change results are comparable for all of the batches. This observation leads to the belief that the addition of the Tetraguard® has more of an affect on the shrinkage than do the fibers. However, in the life span of the concrete, the fibers may decrease the tensile forces in the concrete when cracks start to display and hence provide a better serviceability. The Tetraguard® once again displayed its affects on the early age shrinkage due to the tension release on the air bubbles within the concrete. These values are seen to be above those in the Matrix 7 study; however, it is believed that this is due to the decreased dosage rate in the Final Mixes. The shrinkage results go on after the 7 day mark to once again follow the same length change trends that were seen to be normal in the concrete studies. Figure 5.31 presents the unrestrained length change results over a 56 day period.

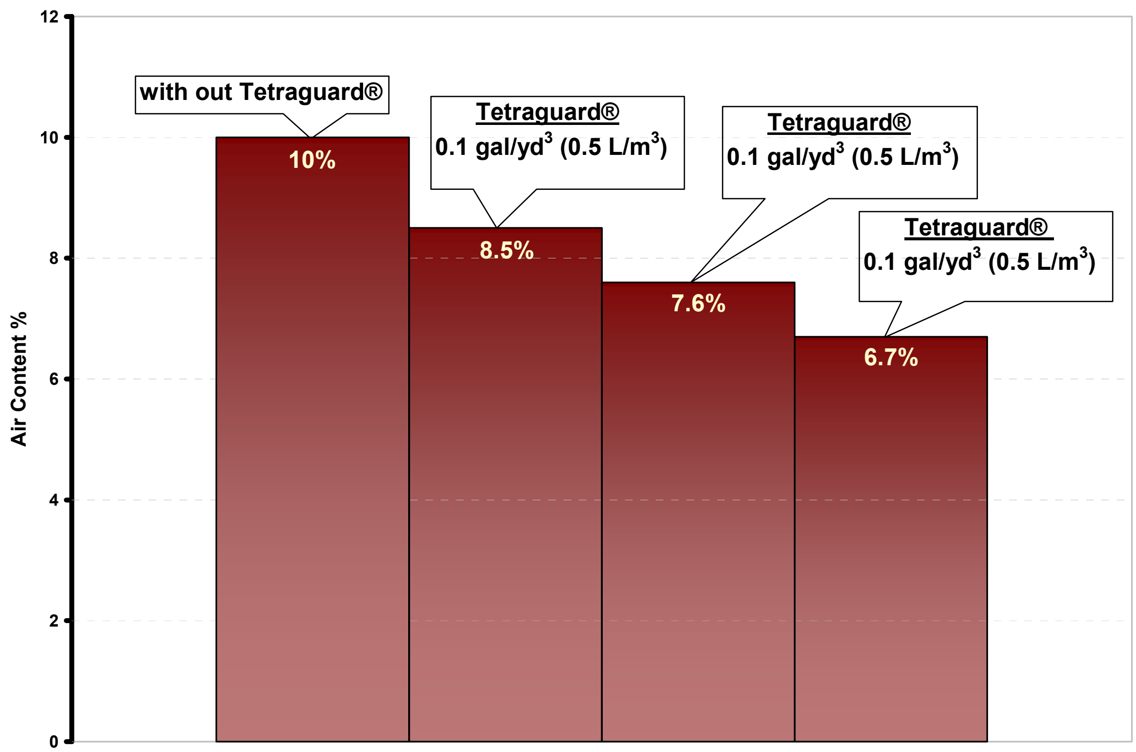
Figure 5. 31 – Unrestrained Length Change of the Final Batches



The shrinkage results produced in the final batches are promising with respect to the overall performance of the concrete. When comparing these results to the Preliminary Batches which are representative of a currently used batch in the field, the final batches are by far superior. An example of this is seen when comparing the range of 28 day length change results of the Final Batches (277-310 in^{-6}/in (m^{-6}/m)) to those of the Preliminary Batches (410-470 in^{-6}/in (m^{-6}/m)), an improvement of over 100 με, or compared to the results of a bridge cast in eastern Oklahoma in 2005 with 28 day shrinkage results of 410 in^{-6}/in (m^{-6}/m). This field data not only backs the validity of the Preliminary Batches, but it also shows the high possibilities of the HPC mixtures developed with this investigation.

Some interesting discoveries were found in these final batches on the affects Tetraguard® has on concrete in addition to its contributions to increased workability and shrinkage reduction. It was found from building off of the previous study that the best method of admixture addition is to add the air-entrainer early and the shrinkage-reducer at the end in small dosages. This in turn allows the air-entrainer to be agitated by the aggregates and fully develop the bubbles throughout the mixing process. Due to the air "killing" nature of the Tetraguard®, it was found best to perform the addition in multiple small dosages as needed. This explains the increased dosage amount found in Batch 40, which included a total of three dosage additions. The air content was taken prior to the Tetraguard® addition as well as after each individual dosage. In Batch 40 with a partial dosage rate of 12.9 fl oz/yd^3 (0.5 L/m^3), the air content dropped approximately 1 to 1.5% each time. Figure 5.32 displays the air content drop of Batch 40 through this process. The results found show that the Tetraguard® can be used as an air content controller of the highly variable entrained air content when provided in these smaller doses. It should be noted that on the other batches only one dosage was added to the mixtures. The air-entrainer and mid-range water-reducer were the variables altered for a better performance though air content and workability. Since one dosage of Tetraguard® provided these mixtures with the desired air content, the multiple dosing was not needed.

Figure 5. 32 – Affects of Tetraguard® on Air Content



The air content levels desired for the final batches were not as mentioned in the original goals of the investigation. After discussing the 8% specification level with ODOT, it was decided that the air content level could be lowered to 6%. This was decided for two reasons. First, ODOT currently implements a 6% air content criteria and does not at this time have significant issues with freeze-thaw. Second, the air content was has a large impact on the length change and strength results. A lower air content requirement makes reaching the required 4000 psi compressive strength easier to achieve.

The slump of the final batches was found similarly for all of the batches around 1 inch. This was mostly due to the amount of mid-range water-reducer added to the mixes. For example, the batches with fibers were found to be extremely thick and sticky. This required large dosages, even over the recommended limits, to be added to produce a batch that was able to be used and to keep the water content constant. Another fresh concrete property with observable comments is the concrete temperature. The concrete temperatures of the final batches were all approximately 80^{o}. This was observed even after adding ice and pre-cooling the aggregates. The researches were left with the concern of whether or not the field production of the mixtures would be able to reach the 75^{o} specification. Early pours are recommended with the possible addition of ice or liquid nitrogen to the batches if the concrete temperature is too high.

An additional batch, 44, was performed after the final four were completed. This batch was an exact duplicate of Batch 40, cement + fly ash, except less of the shrinkage-reducer was used. This is because the air content desired was found without the need of a triple dosage of Tetraguard®. However, the main difference in the batch was the mixing time. It was decided to add an additional 40 minutes on to the concrete mixing time to simulate the truck travel time to the construction site. This resulted in compressive strength and shrinkage results that were comparable. As for the fresh properties, the slump decreased from 1.5 inches to 0.5 inches and the air content dropped from 6.2% to 5.5%. The air content levels found are acceptable for the field construction if the initial levels at the batching plant are at a slightly higher level. As for the low slump, this is a concern that the researchers believe can be handled by the addition of additional mid-range water-reducer.

5.5 Modulus of Elasticity

The modulus of elasticity of all of the batches performed in this investigation was found at 28 days. This data was not directly used in consideration of the mixtures chosen, but instead was used as secondary data and to characterize the mixes. It should be noted that all the mixes followed the same trend. The expected value of approximately 4×10^6 psi (27.6 MPa) was usually seen if the concrete mixtures achieved the necessary 4000 psi compressive strength. If not, it was found to be lower down to 1.7×10^6 psi (11.7 MPa) or higher following the trend of the compressive strength. In addition, some of the modulus of elasticity values were found to be low even if the strength level was met. This was found to be caused by the extensiometer jacket not fully setting into the specimen. This problem was caused by air voids where the screw clamps were located in the specimen not allowing the clamps to fully anchor.

5.6 Chapter Summary

This chapter provided discussion and logic behind the laboratory investigation and its results. The chosen variables for each matrix in the Primary Investigation, Secondary Batches, and the Final Batches were explained. In addition, the major findings in the laboratory investigation were of the validity of the Shilstone method, the affects of Tetraguard®, and the outcome of four HPC mixtures to be used in an actual bridge deck construction. The application of the final mixtures as well as the characterizing test results can be found in Chapter 6 (Field Applications).

CHAPTER 6 – Field Investigation

6.1 Introduction

ODOT's 2004 IBRC project called for three test slabs to be performed prior to the onset of construction. These test slabs were performed on November 24, 2005 at an ODOT field yard in Sayre, Oklahoma. From these slabs, observations were made on the plastic concrete characteristics as well as samples taken to characterize the mixtures. In April and May 2006, the first phase of construction, consisting of the west bound I-40 bridge, was performed. During this process, additional testing was performed as well as observations on the mixtures performance. The following sections highlight these events in more detail.

6.2 Test Slabs

6.2.1 Background

Only three of the four HPC mixtures produced were cast as test slabs due to the contract between ODOT and the Muskogee Bridge Co., the general contractor. It was decided through the investigation and meetings with those parties involved that the three mixtures would consist of the cement+fly ash, cement+fly ash+fibers, and the cement+fibers mixtures. A schedule of the test slabs performed and an image of the test slabs before the concrete was laid are presented in Tables 6.1 and Figure 6.1, respectively.

Table 6. 1 – Schedule of Test Slabs Performed

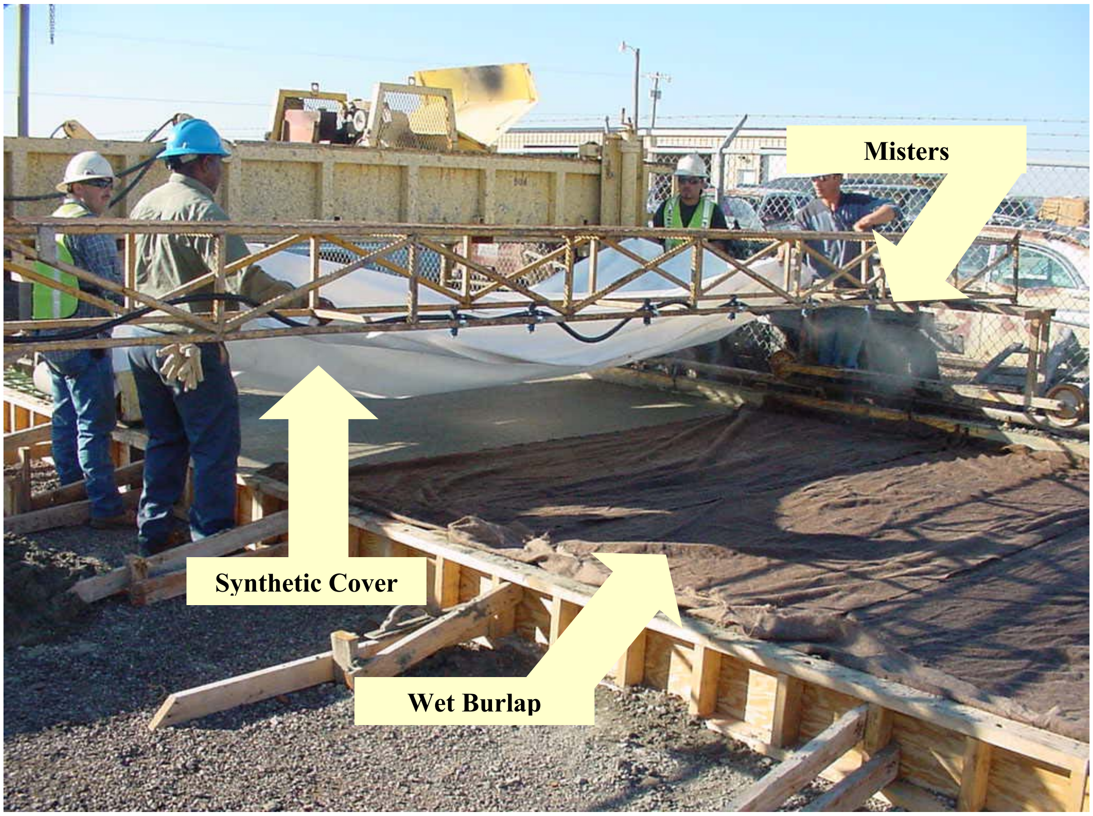
Test Slabs	
1	cement + fly ash
2	cement + fly ash + fibers
3	cement + fibers

Figure 6. 1 – Formwork and Reinforcing of the Test Slabs

The actual test slabs were designed to replicate the conditions of the bridge construction. This included the reinforcement design, the concrete placement and finishing methods, and the curing process to be used during construction. The method of finishing used for this project consisted of a hand vibrator followed by a mechanical finisher with auger that worked the top of the concrete as well as a roller and plate that followed behind to smooth and level. After this was finished, a moist curing of misters, wet burlap, and an experimental synthetic curing sheet were applied for the curing process. After curing, the concrete was applied with a diamond cut tined finish. The reason for all of the provisions at the slabs was to view the difficulties, if any, prior to construction. Figure 6.2 and 6.3 display images of the finishing and curing methods, respectively.

Figure 6. 2 – Mechanical Finisher Used at the Test Slabs

Figure 6. 3 – Curing System Used at the Test Slabs



The actual test slab construction was delayed a couple of weeks due to aggregate issues that arose just prior to the construction date. One of the main focuses of this project is in the aggregate blend used in the mixtures. This entails a close consideration of the distribution of aggregate particles and their corresponding values to the Shilstone Coarseness Factor chart. To ensure this accuracy, sieving of the local aggregates supplied by the concrete batch plant for the research was performed. However, on October 20, 2006 before the test slab construction, gradation data of the aggregate stockpiles that were to be used in the slabs was given to the investigators. The comparison of the two gradations is presented in the percent passing chart in Figure 6.4 and the percent retained chart in Figure 6.5. It can be seen that there are some gaps in the gradation that was to be used for the slabs. The significant particle changes found were in the decrease of the ½ and ¾ inch sizes and an increase in the $^{3}/_{8}$ inch and No. 4 particle sizes. This shows that the new gradation supplied is lacking in the larger quality aggregates and consists of more intermediate sizes. The ¾ and $^{3}/_{8}$ inch particles are not as much of a concern in the percent retained category due to the fact that they balance each other out. However, the ½ inch and No. 4 particles present more of an issue in the gradation comparison.

Figure 6. 4 – Chosen Blend Gradations for the Laboratory and Batch Plant Stockpiles

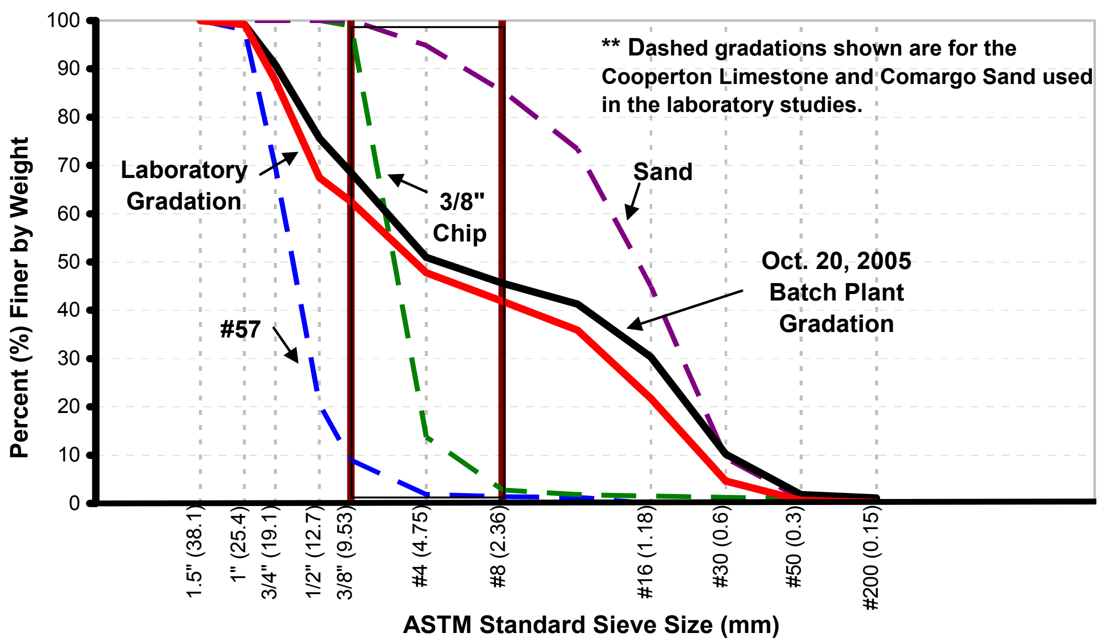
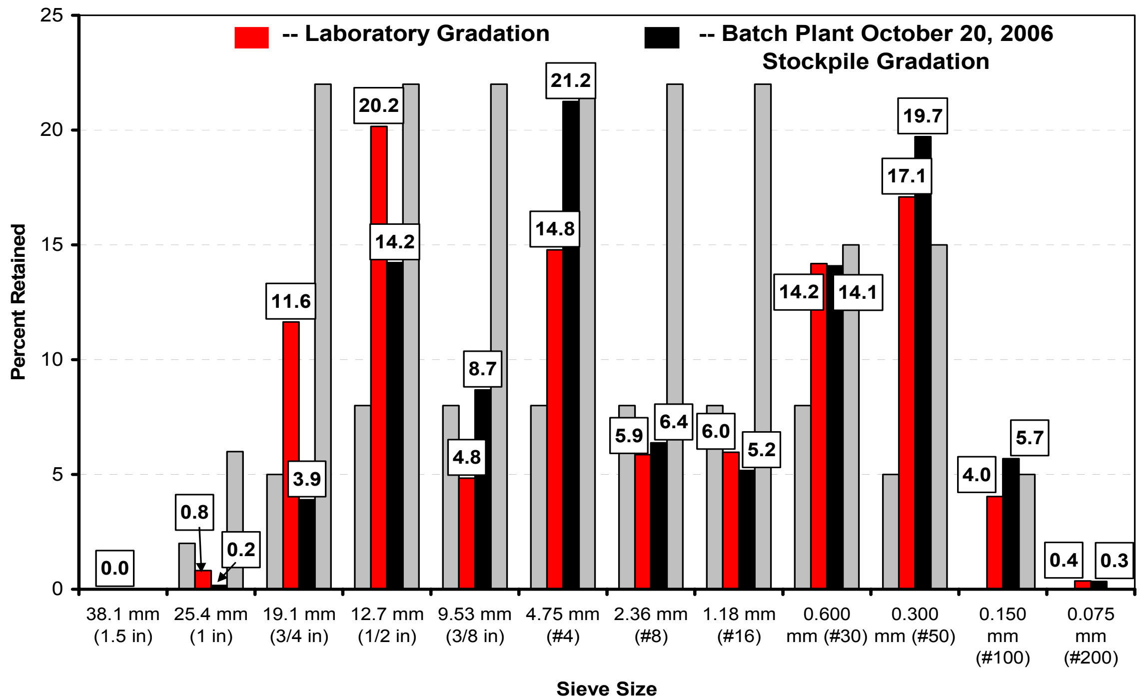
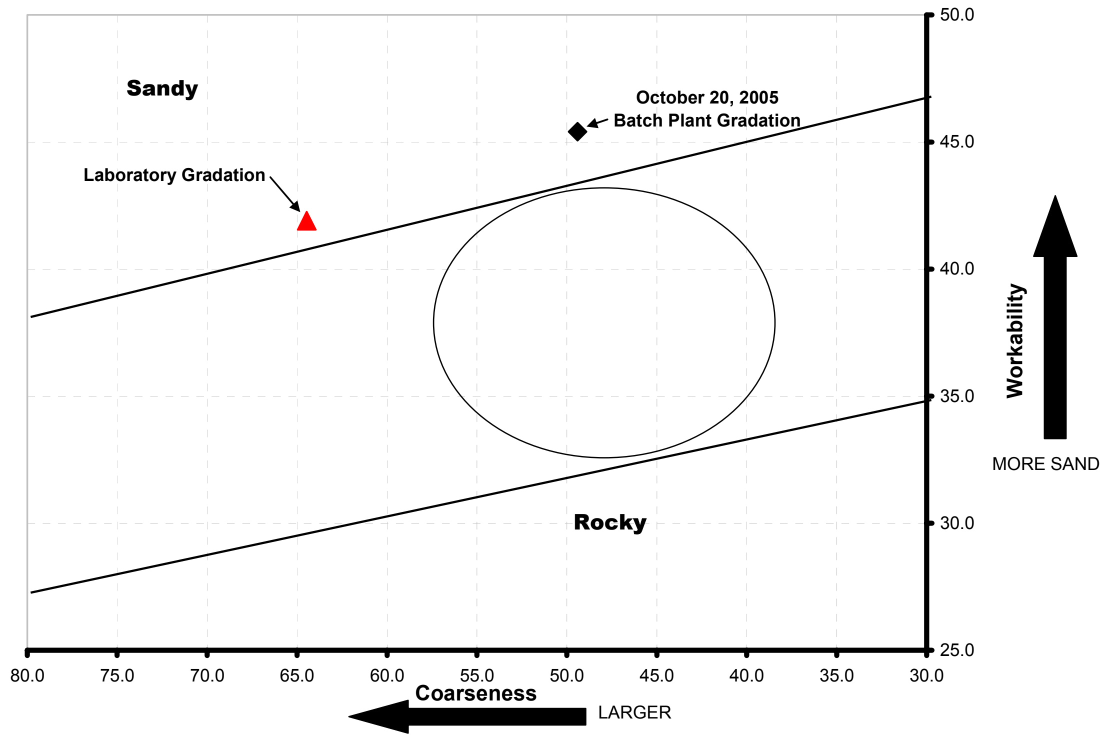


Figure 6. 5 – Percent Retained for the Laboratory and Batch Plant Stockpiles (gray bars represent recommended low and high values provided for the project)



In terms of the Shilstone Coarseness Factor chart, it can easily be seen why this gradation change was a concern to the investigation. Figure 6.6 displays the two gradation blends plotted on the Shilstone Coarseness Factor chart. The shift in the new gradation to the right shows the same lacking in large particle sizes that was mentioned from the percent retained chart. However, the Coarseness Factor chart is concerned with the total coarse, intermediate, and fine particles and does not display which particle sizes have changed.

Figure 6. 6 – Laboratory Gradation and Batch Plant October 20, 2005 Gradation Plotted on the Shilstone Coarseness Factor Chart



It is known that this new gapped gradation presents an additional variable in the field when compared to the laboratory, but after much consideration the investigators decided to proceed with construction using the same 41% (#57 coarse), 11% (3/8" chip), and 48% (sand) blend even with the stockpile gradation change. This was because no new blend could be achieved with the new stockpiles to closely replicate the original Coarseness Factor chart data of the laboratory gradation. In addition, it was determined that the concrete admixtures being used in this research have been seen at this point to control the performance of the HPC mixtures to a much greater extent than the blend.

6.2.2 Construction

Overall, the pour day for the test slabs went well. The first mixture that was poured was the cement+fly ash mix. The contractor decided to use a pump truck for the application process due to preferences on the job site. Figure 6.7 displays the pump truck in action. This application process performed well with a nice mixture described as “flowy” or “slushy”. The concrete consistency was provided by its slump of 3 ½ inches and an 11 ½ % air content.

Figure 6. 7 – Pump Truck Applying the Cement + Fly Ash Mixture to Test Slab 1

The second and third test slabs consisted of the cement+fly ash+fibers and cement+fibers mixtures, respectively. Test slab 2 was attempted to be pumped just as the first slab; however, the mix turned out to be too dry and “sticky” which led to the pump truck clogging. After the pump truck was back pumped, it was decided to apply the two remaining fiber slabs straight from the back of the truck. Figure 6.8 displays the pump truck back pumping the mix.

The truck application process had its own difficulties. The sticky mixture was unable to release from the truck shoot for both of the fiber mixes as well. Figure 6.9 displays the concrete attempting to be released from the truck. With the issues at hand, an addition of approximately 2.5 gal/yd^3 (12.4 L/m^3) of water to the cement+fly ash+fibers and the cement+fibers mixtures was added at the site. After these additions, both test slab fiber mixtures flowed from the truck acceptably with a slump of 5 inches for the cement+fly ash+fibers mix and 3.5 inches for the cement+fibers mix.

It should be noted that this extra water was not a calculated amount of addition, but rather an addition made during construction to continue the process. It was known that the 2.5 gal/yd^3 of additional water may have been more than necessary. The slumps were increased, but it was noticed after the water addition that the increased slump produced was connected to a soupy concrete. However, it was noticed that both concretes dried rather fast in response to the fibers and the extended mixing time needed to arrive at the site. Thus, the amount of addition may have been acceptable, but it is believed that in the future an addition of more water-reducer in attempt to produce a better workability is more beneficial than changing the w/cm. The additional water will most likely affect the long term performance of the concrete, especially in length change.

Figure 6. 8 –Back Pumping of the Pump Truck Boom Due to Being Clogged After Attempting to Pump the Fiber Mixture for Test Slab 2

Figure 6. 9 – Fiber Mixture Clogged In the Mixing Truck after the Pump Truck Attempt and Before the Additional Water

6.2.3 Slab Performance

The necessary tests needed were taken from the slab site. These included the fresh concrete properties in Table 6.2 and the hardened concrete properties in Table 6.3. The specimens obtained from the slabs were allowed to cure on-site for 1 day and then brought to the laboratory where they finished their curing process exposed in an environmentally controlled chamber. The mix design used at the batch plant before any alterations is presented in Appendix D. In addition, the data sheets for the testing results for all tests are found in Appendix C.

The slumps found at the slabs were manageable. The investigators were not informed at the beginning of the research of the method of construction so that specific slumps could be developed but rather to aim for a slump of 1 to 3 inches. The high slump for test slab 1 aided in the pump truck application; although, the fiber mixes do not allow this type of construction. A drop bucket or shoot application with the slumps of the fiber mixes after the alterations will be suitable in the construction of the bridge and was deemed acceptable.

Table 6. 2 – Fresh Concrete Properties Obtained at the Test Slabs
(Values in Red are of concern due to the special provisions)

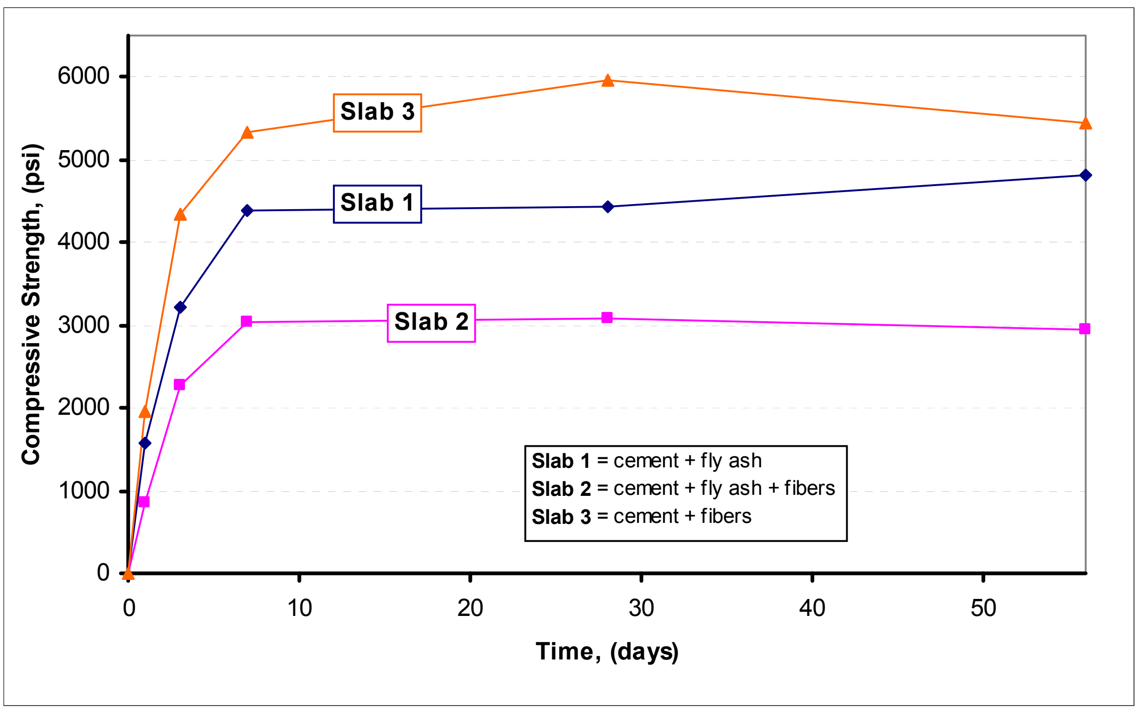
Cement + Fly Ash Test Slab 1		
Air Temperature	78	^{o}F
Relative Humidity	37	%
Concrete Temperature	80	^{o}F
Slump	3.5	in.
Air Content	11.5	%
Unit Weight	135.7	lb/ft^3
Cement + Fly Ash + Fibers Test Slab 2		
Air Temperature	78	^{o}F
Relative Humidity	38	%
Concrete Temperature	78	^{o}F
Slump	5.0	in.
Air Content	13.5	%
Unit Weight	129.7	lb/ft^3
Cement + Fibers Test Slab 3		
Air Temperature	78	^{o}F
Relative Humidity	38	%
Concrete Temperature	76	^{o}F
Slump	3.5	in.
Air Content	9.5	%
Unit Weight	137.7	lb/ft^3

Table 6. 3 – Hardened Concrete Properties of the Test Slabs

Cement + Fly Ash Test Slab 1			
Compressive Strength	1 day	1578	psi
	3 days	3211	psi
	7 days	4378	psi
	28 days	4425	psi
	56 days	4807	psi
Shrinkage		313	in^{-6} / in
Modulus of Elasticity		3.45E+06	psi
Cement + Fly Ash + Fibers Test Slab 2			
Compressive Strength	1 day	855	psi
	3 days	2280	psi
	7 days	3030	psi
	28 days	3082	psi
	56 days	2942	psi
Shrinkage		435	in^{-6} / in
Modulus of Elasticity		2.53E+06	psi
Cement + Fibers Test Slab 3			
Compressive Strength	1 day	1950	psi
	3 days	4352	psi
	7 days	5338	psi
	28 days	5969	psi
	56 days	5444	psi
Shrinkage		400	in^{-6} / in
Modulus of Elasticity		3.38E+06	psi

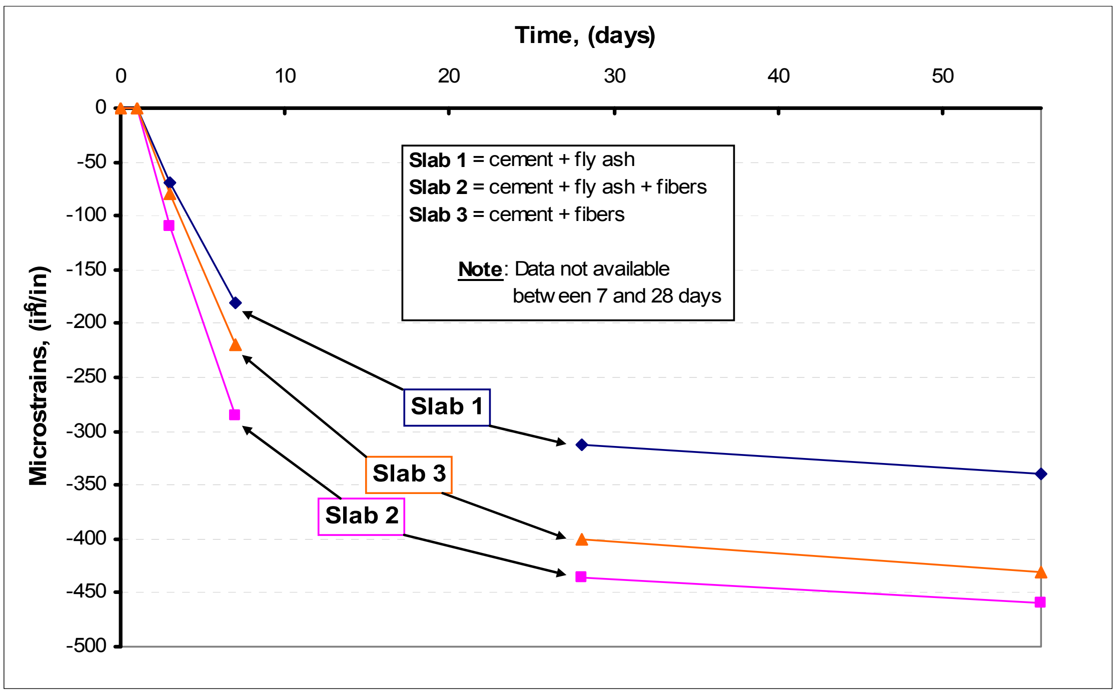
The air contents were an issue for all of the mixtures since a 6 to 8% range was the goal. Unfortunately every one of the test slabs was higher. The high results did bring some promising data nevertheless. In the laboratory, a compressive strength above 4000 psi was hard to achieve with air contents at the levels seen at the slabs. Surprisingly, all but one of the test slabs cleared this level of strength. Test slab 2, which did not meet strength, contained the highest air content as well, 13%. Thus, the air content affects on the concrete strength were seen just as in the research. Figure 6.10 displays a plot of the compressive strength test results that were found for the test slabs over a 56 day period.

Figure 6. 10 – Compressive Strength of the Test Slabs



The unrestrained length change results produced are a little higher than was desired; however, they are still below the normal construction shrinkage results. Thus, it is believed that if the air content is lowered to the desired levels that the shrinkage results will be much lower. This once again displays the importance of the air content effects. Figure 6.11 displays a plot of the unrestrained length change results of the test slabs over a 56 day period.

Figure 6. 11 – Unrestrained Length Change of the Test Slabs



Another concern, which was not discussed among those involved to any great extent, was the concrete temperature. These slabs were constructed in November with cooler ambient temperatures. Even then the concrete values, although low, were still just above the project specifications of 75^{o}. This was a concern since the bridge construction date will be in the spring or summer. It is recommended to perform any additional construction in the morning and possibly substituting some of the mass with ice to reach this concrete temperature goal.

An additional test was performed on the test slabs. This test was the Air Void Analysis (AVA). The AVA samples were taken by the investigators for each mixture at the site as the concrete left the truck, as it was placed, and from the finished slab. Figure 6.12 displays an image of sampling from the finished slab being performed. These specimens were then delivered to a contracted laboratory for AVA analysis. The results from these tests are found in Appendix E.

Figure 6. 12 – AVA Sampling from the Test Slab

It was noticed that the actual air content readings found by ODOT at the site were considerably higher than those found during the AVA testing. Table 6.4 displays the air content values. However, this is reasonable due to the large air bubbles may have been lost from vibrations during sampling and when placing the specimens in the glycol of the AVA test. Also, the AVA test is measuring data from the mortar and not the concrete. Thus, some variation was to be expected. In addition, the large air bubbles are not the main concern for freeze-thaw issues.

Table 6. 4 – Air Content Data from the Slab Site and from the AVA Test

		Air Contents			
		ODOT	AVA		
Slab			Out of Truck	During Application	From the Slab
1	cement+fly ash	11	7.6	7.4	5.5
2	cement+fly ash+fibers	13.5	4.8	7.5	6.6
3	cement+fibers	9.5	---	5.2	4.5

It should be noted that when the AVA specimens for the fiber batches were taken the syringes would not accept the mortar. Thus these specimens had to be taken by hand packing. It was deemed by the contracted researcher that this process was acceptable especially for the circumstance found with the fibers. Figure 6.13 displays an image of the troubles found with sampling the fiber mixtures.

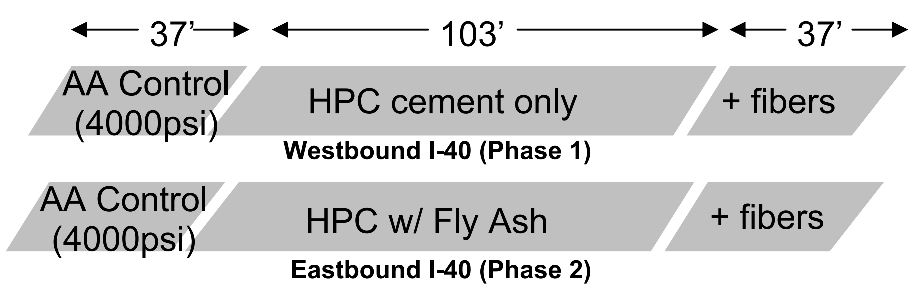
Figure 6. 13 – Original Matting Problems with Fiber Mixtures in AVA Testing

6.3 Bridge Deck Construction

6.3.1 Background

On April 26, 2006, the first phase of the bridge deck replacement associated with this project was performed on I-40 westbound over I-40 business loop at Sayre, Oklahoma. This deck pour consisted of three skewed slabs: two 37 feet long end slabs and one 103 feet long center slab. Figure 6.14 displays the bridge deck construction layout.

Figure 6. 14 – Bridge Deck Mixture Layout



The first two spans, starting from the west end, were poured in one day and the last span in another. The first span (west end) was poured with the control mixture, a typical cement only ODOT AA (4000 psi) concrete mix. The remaining long center span was poured with the cement only HPC mixture and the final end span was poured with the cement+fibers HPC mixture. The final span was to be poured during the same day as the other spans; however, due to complications discussed in the following construction section, the final span was pushed to the succeeding day and then to the following week.

6.3.2 Construction

On the day of construction, the researchers set up a testing station at the Dolese Bros. batch plant located in Elk City, Oklahoma approximately 20 minute from the construction site. This stationing allowed the researchers to take the necessary tests and data as well as tell whether or not the batches in the truck would meet the specifications before they were released to the job site. At the batch plant, the results produced were extremely good. However, it was found that the air content, concrete temperature, and workability at the construction site were varying greatly from the plant and causing complications.

The first two spans were producing fresh concrete data in the range of the specifications and were looking promising. However, those values were taken at the batch plant. At the bridge site the concrete was becoming very dry and in turn clogging the pump truck. In addition, the air contents and concrete temperatures were rising. These issues were deemed to be directly connected to the travel time. Once several trucks were rejected and the issue of having excess trucks at the bridge site, which created additional mixing time, was corrected, the first span began to be constructed with a better quality concrete. However, the second span with the cement only HPC was still having negative results.

The affects of an increased mixing time due to travel distance was studied in a laboratory test batch, Batch 44, using a mixing time of approximately 40 minutes. However, this test did not show any significant problems except for a possible slump loss. This led to new field issues being a problem with the HPC mixtures. It was hypothesized that the shrinkage-reducer (Tetraguard® AS20) was reacting with the other two admixtures (Polyheed® 1020 and the air-entrainer)) during the 20 minute drive from the batch plant in a manner that is not fully understood at this time. Several variables or even a combination of variables such as temperature, mixing time, agitation from the travel, dosage rates, and chemical content and reactions of the admixtures may be playing a role in the effects seen with the admixtures. No matter which variables were causing the problem, approximately 20 to 30 minutes after the mixing trucks left the batch plant, the concrete batches would start to rapidly dry out. This led to rapid changes in the mixing sequence and dosage rates. After several rejected trucks due to workability and air content, the University of Oklahoma researchers decided to have the mixtures batched at the plant as normal; however, the mid-range water-reducer dosage rate was increased to 100 fl oz/yd^3 from 54.1 fl oz/yd^3 with approximately 64 fl oz//yd^3 of this being added at the bridge site with the Tetraguard®. The additional mid-range water-reducer dosage rate provided a little more workable of a mix upon arrival at the site. Furthermore, the Tetraguard® addition that was made at the bridge allowed the Tetraguard® and air-entrainer time before there drying effects occurred, and the addition of the last approximately 36 fl oz/yd^3 of air-entrainer at the site provided the additional workability for the pump truck and sufficient amount of time to get the concrete placed. After these changes, the HPC cement only span was pumped and finished with a much better performance. Figure 6.15 displays an image of the cement only HPC being applied through the pump truck to slab 2.

Additional observations that were later made after examination. It was noticed that the first couple of trucks to be rejected from span 2 were batched with a much lower mid-range water-reducer rate than was called for in the mix design. Even with this being the original reason for the dry concrete batches, the alterations were needed to provide the necessary consistency. Also, the air-entrainer used during construction was a product of W.R. Grace instead of the Master Builders Inc. MB AE™ 90 air-entrainer that was used through out the research. No studies were performed with this alternate product and it can not be determined at this time if the Grace product reacts in a different manner with the other admixtures.

Figure 6. 15 – The Pump Truck Being Used in Construction of Span 2

The third span was attempted to be poured the following day with the same partial addition of the mid-range water-reducer and full dosage of shrinkage-reducer on site. For this batch the pump truck was attempted to be used again by the decision of the contractor. This application process quickly failed due to the thick consistency of the mix including fibers. At this point, a crane and bucket drop application was then decided to be used. It was found that the mix was still to dry to be vibrated and finished when applied; furthermore, the concrete tended to stick to the sides of the drop bucket. An image of a sample of the dry fiber mix is presented in Figure 6.16. This led to adding approximately 3.1 gal/yd^3 of water to the mixture on site which in turn developed a workable mix; however, the mix was visually seen to have separation bleeding and was rejected.

Figure 6. 16 – Sample from an Original Dry Fiber Mix at the Bridge Site

The second batch was mixed with approximately 12 fl oz/yd^3 of mid-range water-reducer and 1.9 gal/yd^3 of water that was added on arrival. At this point the workability was found to be suitable for bucket application, but the air content was at 11½% which was above the specifications of 8% for the project. Thus, the batch was rejected. The third batch was mixed with 8 fl oz/yd^3 of mid-range water-reducer and 1.9 gal/yd^3 of water were added at the site. This produced a batch with an air content of 7.4% and a consistency suitable for bucket application. However, concerns were developed by those present whether it was acceptable due to a concrete temperature of 80^{o}F, which is over the 75^{o}F specified in the special provisions. It was decided that the temperature would not be capable of being below the specifications without possible special measures being taken or by batching in the morning hours due to the ambient temperature was too high so work was suspended for the day.

Construction was continued on the morning of May 2, 2006 with some changes made to the mix design to aid in the problems achieved during the prior attempt. The first batch that arrived on the site was produced using 8 fl oz/yd^3 of air-entrainer and 3 bags of fibers instead of the 5 bags used during the last attempt. This batch produced an air content of 10%, a slump of 5¼ inches, and a concrete temperature of 72^o. Unfortunately, the batch was rejected since the air content was above the 8% specifications. The next batch was mixed with 5 fl oz/yd^3 of air-entrainer. This produced an air content of approximately 11½% directly off the back of the mixing truck. However, when the air was remeasured with a more consistent concrete sample from the bulk of the batch, an air content of 7.2% to 8% was found. With this and a concrete temperature of 72^{o}F, the batch was accepted. Nevertheless, the mix design was changed again to include 4 fl oz/yd^3 of air-entrainer to ensure that the air content would not rise above the 8% mark on the succeeding batches. An image of the fiber mix that was used at the end of the mix alterations is presented in Figure 6.17 as well as an image of the drop bucket application method in Figure 6.18. The finished product of the Phase I bridge construction can be seen in Figure 6.19.

Figure 6. 17 – Sample of the Improved Fiber Mixture Used in the Construction of Span 3

Figure 6. 18 – The Drop Bucket Being Used for the Application of the Fiber Mixture on Span 3

Figure 6. 19– Phase I Bridge Deck after Construction

6.3.3 Concrete Performance

Tests and specimens were taken during the construction process. These tests include those for the fresh concrete properties displayed in Table 6.5 and the hardened concrete properties presented in Table 6.6. All of the specimens taken from the site were allowed to cure for 24 hours at the bridge site except for the fibers batch which cured at the site for 3 days. After these periods, the specimens were then open air cured in an environmentally controlled chamber at the laboratory for the remainder of the testing. It should also be noted that the bridge deck testing is still in progress and the data has only been obtained for the 28 day readings. The tests results presented in this section were found by the researchers. For the results found by the investigators, ODOT, and Muskogee Bridge Company see Appencices C, F, and G, respectively. The Muskogee Bridge Co. test data sheets and the Dolese Bros. batch tickets are also provided in Appendices H and I.

Table 6. 5 – Concrete Values Obtained at During Bridge Construction

ODOT AA **(with out fly ash)** **Span 1**		
Air Temperature	61	°F
Relative Humidity	48	%
Concrete Temperature	65	°F
Slump	3-5	in.
Air Content	7.2-9	%
cement only **Span 2**		
Air Temperature	62	°F
Relative Humidity	48	%
Concrete Temperature	---	°F
Slump	4-7.5	in.
Air Content	6.4-7	%
cement + fibers **Span 3**		
Air Temperature	71	°F
Relative Humidity	89	%
Concrete Temperature	75	°F
Slump	5.0	in.
Air Content	7.6-8	%

Table 6. 6 – Hardened Concrete Properties of the First Bridge Construction

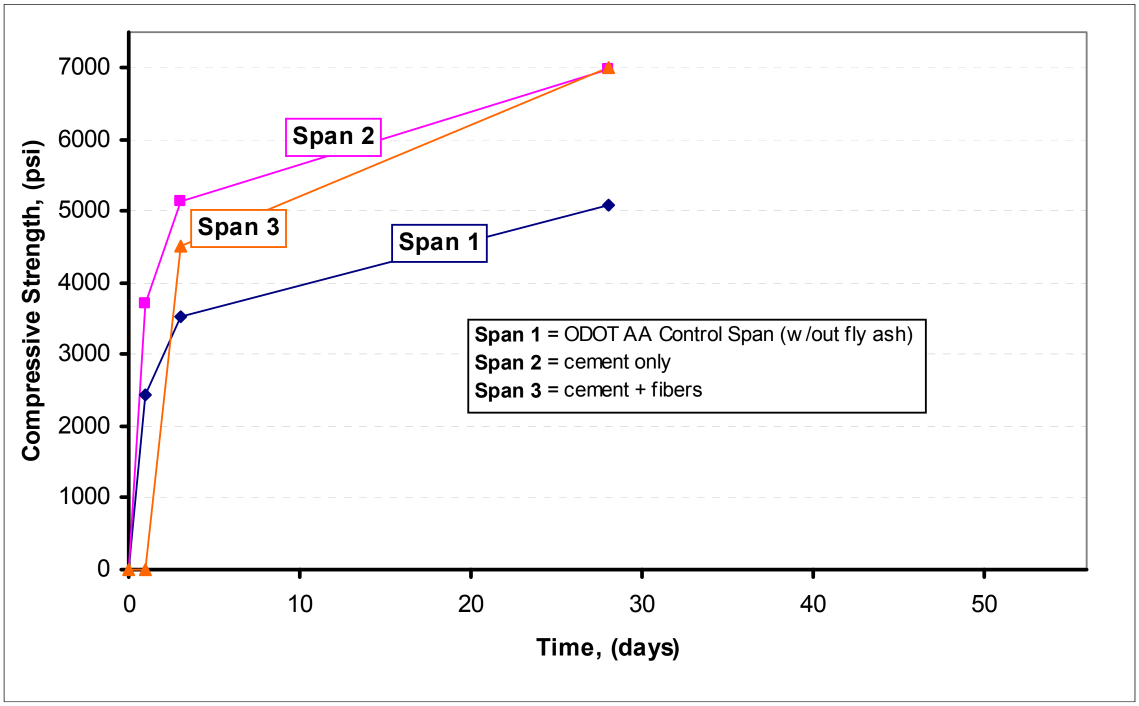
ODOT AA (WITH OUT FLY ASH) **Span 1**			
Compressive Strength	1 day	2442	psi
	3 days	5411	psi
	28 days	5081	psi
Splitting Tensile	28 days	1679	psi
Shrinkage	28 days	273	in^{-6} / in
Modulus of Elasticity	28 days	4.07E+06	psi
Cement only Span 2			
Compressive Strength	1 day	3712	psi
	3 days	5142	psi
	28 days	6976	psi
Splitting Tensile	28 days	2131	psi
Shrinkage	28 days	260	in^{-6} / in
Modulus of Elasticity	28 days	4.29E+06	psi
Cement + Fibers Span 3			
Compressive Strength	1 day	N/A	
	3 days	4526	psi
	28 days	7004	psi
Splitting Tensile	28 days	1788	psi
Shrinkage	28 days	250	in^{-6} / in
Modulus of Elasticity	28 days	4.51E+06	psi

** This values is directly linked to the assumed initial 24 hour value explained in the text.

After the difficulties mentioned in the construction section were solved, the fresh concrete properties desired were achieved. This included concrete temperatures below the 75°F goal, which were found to be achieved easily if the batching was performed during the morning hours before the ambient temperatures were too high. Also, adding the mentioned admixtures at the site helped to some extent in keeping the temperature down for reasons that are not fully understood at this time. More importantly, these late admixture additions and some dosage rate changes allowed slumps and air contents desired to be achieved. With the complex nature of these admixtures in the mixes and their interaction with the mixing time, it is recommended that more research be performed to fully understand their reactions before additional batching takes place.

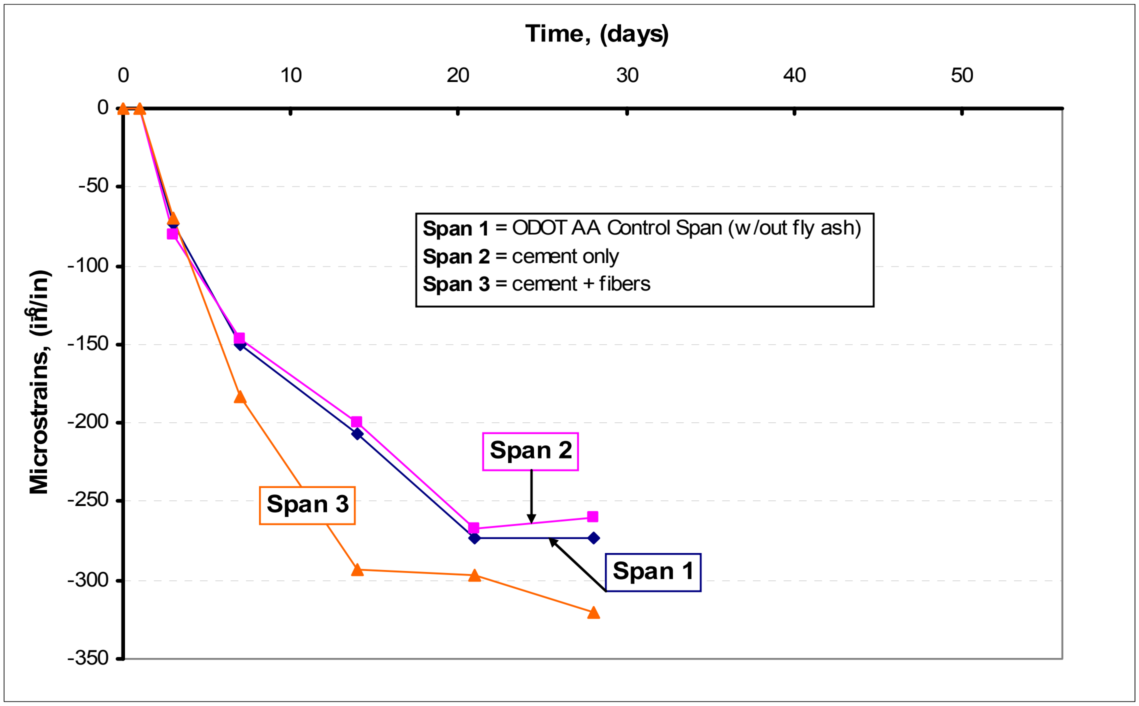
All of the compressive strength results found from the bridge deck cleared the 4000 psi goal. In fact, as seen in Figure 6.20, the two HPC mixtures climbed to a compressive strength of approximately 7000 psi. This level of strength, just as the test slabs, is much higher than expected with the air content levels developed. Noticeably, the AA control mix did not reach 4000 psi until after the 3 day readings where it sits approximately 2000 psi less than the HPC mixes. It was expected that high early strengths would be found due to the mixes containing all cement and no cementitious materials, but definite conclusions on the reasons for the mixtures differences are not yet understood at this time due to all the difficulties found during construction. However, it is hard not to notice both of the HPC mixes are both stronger than the control span.

Figure 6. 20 – Compressive Strength from the Bridge Construction



The unrestrained length change results are even harder to compare than the compressive strength. This is due to third span with fibers mix not being initialized at the 24 hour period. Thus, the 24 hour shrinkage results for span 3, seen in Figure 6.21, were forced to approximately the same results as the first two spans to provide some sort of measure among them all. With this it can be seen that the fiber mixture is shrinking more than the other two spans which are performing similarly. Due to the lack of data for the early age shrinkage affect on span 3, definite conclusions can not be made at this time on the comparative performance. However, all three batches at this time are performing with respectably low shrinkage results. Especially with the amount of air contained within each.

Figure 6. 21 – Unrestrained Length Change from the Bridge Construction



The splitting tensile test was performed on the bridge deck specimens at the 28 day period in addition to the normal hardened concrete test. The results found from these tests are surprising. It was expected, as with normal concrete, that the tensile strength would be approximately 10% of the compressive strength. However, the bridge specimens tested showed a tensile strength approximately 30% of the compressive strength. An additional surprise is that the tensile strength of the fiber mix is at approximately 25% of the compressive strength. It was believed that this mix would be more ductile and develop much higher tensile readings than the other mixes. This characteristic of the fibers mixture may have been influenced by the decreased fiber content contained and the difference in the amount of time the fiber mix specimens were allowed to cure on site. None the less, it is hard to rely totally on the values found for any of the batches due to all the variables and changes made during construction.

Additional samples were taken at the site to perform freeze-thaw testing. These samples consisted of prisms 4x4x15 inches in size. The freeze-thaw testing is still currently under way and unfortunately no data can be presented at this time. However, it can be noted that the procedures being used follows ASTM C 666 with some modifications. These modifications were made due issues found with the transverse frequency reader at the laboratory. Arrangements with ODOT to use their equipment for the readings were made and thus the testing was once again in progress. Due to these issues the initial transverse frequency readings were forced to be taken at 37 days for the AA and the HPC cement only mixes and at 31 days for the HPC cement+fibers mix instead of the recommended 28 day start time. These changes were noted and the freeze-thaw cycling began after the initial readings.

It should also be recognized that some modifications have been made to the cycle process due to the readings needing to be taken at the ODOT Materials Division in Oklahoma City, approximately a 20 minute drive from the freeze-thaw chamber in the laboratory. To achieve these readings and not interrupt the temperature range of 0^{o}F to 40^{o}F and the cycle process, the specimens are removed from the chamber in the thawed state, approximately 40^{o}F, and placed in coolers with an ice and water mixture where the temperature is then occasionally measure to ensure that the temperature does not become to high or low during the whole process. The reason that the temperature is maintained at approximately 40^{o}F instead of a frozen state, which is the recommend state the specimens should be in when removed from the chamber for any length of time by the ASTM standards, is that the reading must be performed in the thawed state. To be able to transport the specimens frozen, then thaw for reading, and then freeze for transporting back was deemed more of an issue to the cycling than the method used.   Thus, the specimens are transported and tested in the discussed manner. As soon as the specimens are brought back to the laboratory, they are replaced into the chamber and set to be cycled again. It should be noted that the specimens are rotated and flipped in the chamber after each reading to ensure that each specimen is exposed to the same conditions in the chamber.

6.4 Field Investigation Remarks

Definite conclusions can not be made at this time for the results found at the test slabs or the first phase of the bridge deck construction. This is first of all because the testing is still in progress for the samples taken from the bridge deck, and secondly because the complications found in the field are new characteristics that were not fully seen in the laboratory.

It was noticed that the same mix design from the slabs was used at the bridge construction with out any modifications. This developed the first phase of construction as an additional testing ground where additional alterations were made instead of after the test slabs for the air and workability. However, the new rapid drying problems of the mixes were not seen at the test slabs. These problems started occurring during construction. This unpredictable behavior of the HPC mixtures leads to the conclusion that more investigations should be performed to fully understand the combinations and variables present.

As for the performance of the fiber mixtures, it has not been seen that these mixes produce any benefits in the laboratory and field tests so far. However, the long term benefits in durability and serviceability are not yet known. The fibers are recommended to have further research in workability and their interaction with other variables.

The second phase of construction with the fly ash mixes is expected to be performed with fewer complications. This is due to the concrete characteristics and necessary constituent dosages being realized during the first phase and additional concrete testing that is currently being performed. With these new findings, the HPC mixtures may be deemed more applicable for construction practices including the admixtures and fibers. As was mentioned in the chapter 2 in the discussion of HPC, these special mixes are not widely used due to a lack of knowledge and information on their behavior. Thus, this project was predicted to have some complications due to the newness of the mixes. Once the complications are worked out at the local level and the long term durability and serviceability of the concrete are improved, the adoption of future HPC mixtures will become more common in construction practice.

CHAPTER 7 – Conclusions and Recommendations

7.1 Conclusions

- Medium to low range shrinkage and high compressive strengths with little to no cracks can be achieved in concrete.

- Air entrainment was one of the major variables in this investigation. Increased air content is linked to lower compressive strengths and increased shrinkage.

- In the laboratory, the required 4000 psi compressive strength was difficult to reach with air contents above 6%; however, in the field the strengths were higher for a given air content and the required 4000 psi compressive strength was achieved.

- Increasing the cementitious materials content while leaving the air entrainment ratio constant increases the air content of the batches. It is unclear at this time whether the decrease in strength and increase in shrinkage is caused by the increased cementitious materials content, air content, or a combination of the two.

- In the laboratory, the air contents produced in the concretes while holding the air entrainment ratio constant were seen to increase with the w/cm.

- The aggregate blend was difficult to analyze in this investigation due to the multiple variables present, such as admixtures and air contents,

- Aggregates available for concrete production may not be able to be blended to the desired particle distribution due to gap gradations in the available aggregates.

- The Shilstone Coarseness Factor chart did not perform as designed. From the data obtained in this investigation, it is difficult to develop an adequate conclusion. This is due to the all of the variables in the concretes, including air content, creating further changes in the mixtures. Additionally, it is unclear at this time how and to what extent the admixtures are actually affecting the mixtures.

- An increasing DRUW trend was found as the Shilstone Coarseness and Workability Factors increased.

- When blending the #57 coarse limestone and quartz sand, the 3/8 inch chip blend compared to the #2 coarse aggregate was found to have better workability and particle distribution.

- The chosen blend region of the Shilstone Coarseness Factor chart was located near the aggregate blend used currently in Oklahoma concrete practice today.

- The addition of fibers to concrete showed a tendency to lower the air content of the concrete in this research. The fiber mixes also reduced in shrinkage and increased in strength.

- The fiber mixtures were found to be very dry, “matted”, and “sticky”.

- The shrinkage-reducer Tetraguard® was found to decrease the air content of the concrete drastically, reduced unrestrained-length change and increased compressive strengths. The initial shrinkage results were affected the most. In general very little shrinkage was found till approximately the 7 to 14 day curing period.

- No matter how much Tetraguard® was added as a single dose the concrete developed approximately a 3% air content. However, it was found that if the Tetraguard® was added in small repeated dosages, an increased air content could be achieved.

- There is no noticeable advantage for the maximum 75^{o}F concrete temperature set for this project. The temperature is difficult to achieve and no beneficial results have been noted.

- During construction, the materials used were seen to react differently than in the laboratory. It was found that the mixtures were not only developing higher air contents, but they were also changing their behavior properties at about 30 minutes in an undesirable way. At thirty minutes the concrete would rapidly stiffen and start to dry, making unpumpable and in some cases unworkable.

7.2 Recommendations

- ODOT has observed no significant problems with freeze-thaw in Oklahoma with concretes containing 6% air prior to this investigation. Since increased air content is linked to both increased shrinkage and lower compressive strengths, which has a direct correlation with tensile strength, it is recommended that air contents above 6% should not be used.

- It is difficult to produce any definite conclusions or comparisons on the cementitious materials study due to the variable contents. Additional studies should be conducted to further understand their affects.

- Additional research is needed on the blend of the aggregate used and not just the aggregate stockpiles available in Oklahoma. This means that an intermediate aggregate may be necessary. To do this some method of analyzing the concrete aggregate particle size distribution should be used to aid in the focus on the aggregate blends. A variety of methods are available for this including the modified 0.45 power chart, 8-18 rule, percent passing charts, and percent retained charts.

- To more adequately analyze the Shilstone Coarseness Factor chart, it is recommended to test with local materials to see the actual trend areas that are produced. This is due to the uncertainties remaining on what variables are contributing to the concrete characteristics as well as how the admixtures are actually affecting the mixtures.

- It is recommended to focus the aggregate blend choice at this time on the DRUW. The Shilstone Factor chart may be used as a good reference to what regions are desirable for this. This can be seen in the focused Shilstone area containing the highest DRUW. This area was also located near the currently used blend in construction. However, the blend chosen developed a DRUW higher than the one currently in use.

- Until further studies on the Shilstone method make it easier, it should be used with caution. This additional research should start with the Shilstone and aggregate studies with similar admixtures and materials to those used in Shilstone's investigations. When a conclusion can be made, the additional matrix studies (air-entrainer, cementitious materials, w/cm, etc.) should then be tested. This will create more reliable data to compare directly to Shilstone's research. Additionally, it is recommended that the air-entrainment study should be performed last due to the many variables that affect the air-entrainer's performance.

- Further research is needed for the fiber reinforced batches to determine if the affects developed were caused by the fibers, air content, or a combination of both.

- The use of the fiber entrained mixes in actual construction should include additional mid-range water-reducer to reduce the tendency for dry, "matted" or a "sticky" consistency. The mid-range water-reducer should be increased so that the w/cm is not altered unless further research on the w/cm is performed.

- Due to the fiber mixes having harsh workability and not displaying overwhelming improvements in the hardened concrete, it is believed that the other variables present overwhelm any benefits that the fibers have to offer. However, it is not known at this time if the fibers will add any long term durability and serviceability through characteristic plastic breaks, tensile stress relief during cracking, or any other properties that they have to contribute. Further research on the use of fibers with the different variables should be performed.

- The shrinkage from time zero test developed at the University of Oklahoma should be used to better characterize the early shrinkage results displayed in the mixtures containing Tetraguard®.

- In the final mixtures developed in this research, it is recommended to use a multiple dosage rates of 155.1 fl oz/yd^3 (6.0 L/m^3) as needed. This “trickling” affect allows the Tetraguard® to be added while providing a method for controlling the air content. However, further research is needed to more fully understand the relationship between the Tetraguard® and the air-entrainer as well as how to accurately perform the “trickle” dosage of Tetraguard® in full scale batching.

- Additional research is recommended to see if the approximately 3% air content and reduced shrinkage that is found with the Tetraguard® can supply the needed durability for concretes with exposure to environmental affects. Currently, the concretes being used have a higher shrinkage level, but are required to have 6% air content to aid in durability.

- It is recommended that a low concrete temperature be achieved; although, further research is necessary to deem whether the $75^{o}F$ maximum set for this project is reasonable.

- In future projects like this one, it is recommended for all of the parties involved to increase the communication level. This could potentially decrease the amount of concrete rejected, the amount of time to construct, increase the likelihood that the mix design meets all criteria such as pumpability and decrease the amount of last minute adjustments.

- The batch size of the trucks is recommended to be delivered in an experimental batching like this in 4 yd^3 batches.

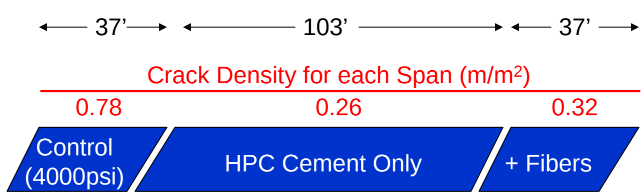
- Not only does additional research need to be conducted on the admixtures used in this investigation, but due to a different air-entrainer used in the field, additional research is necessary to develop conclusions on the differences.

Oklahoma Bridge Deck Crack Survey

Monday, November 19, 2007

This crack deck survey was conducted by Chris Ramseyer and Jason Giebler on 10/25/2007 - The raw data was sent to Dr.Darwin at KU and his team reduced the raw data into this format. Conclusion - all four of the test slabs show less cracking when compared to the control slabs. The East bound bridge has less cracking then the Westbound for all cases including the control spans. The HPC with flyash and fibers had the least cracking.

WB Bridge Layout and Crack Densities



Westbound I-40 (Phase I)

Entire Bridge Crack Density: 0.38 m/m^2

2

EB Bridge Layout and Crack Densities

37' | 103' | 37'

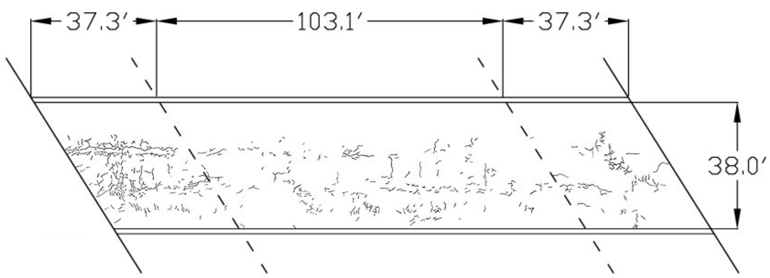
Crack Density for each Span (m/m^2)

Control (4000psi)	HPC Cement Only + Fly Ash	+ Fibers
0.45	0.09	0.06

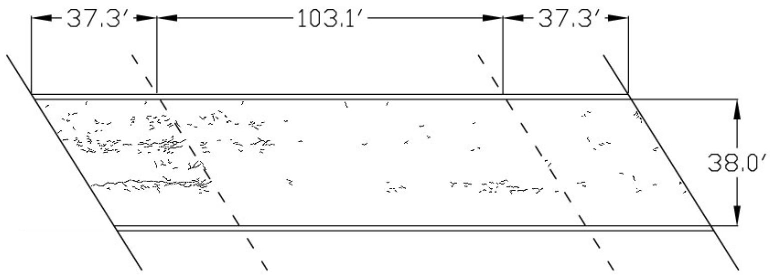
Eastbound I-40 (Phase II)

Entire Bridge Crack Density: 0.16 m/m^2

WB I-40 over Business I-40 Crack Map



EB I-40 over Business I-40 Crack Map



5

37’ 103’ 37’

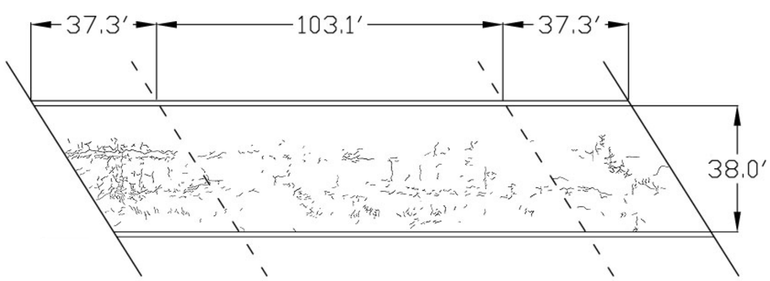
Crack Density for each Span (m/m^2)

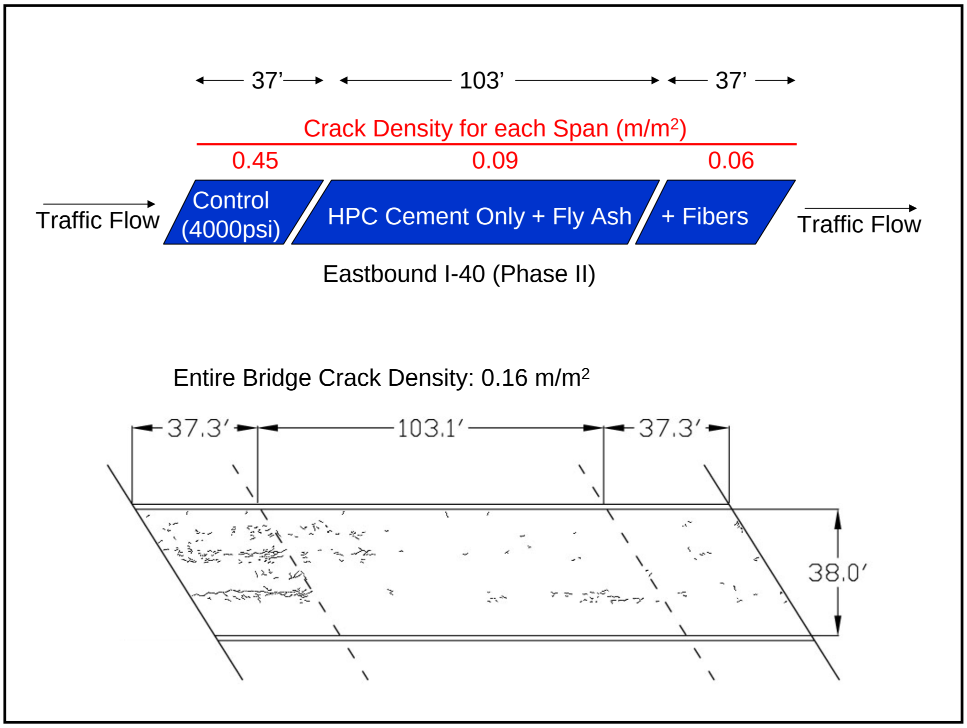
Control (4000psi)	HPC Cement Only	+ Fibers
0.78	0.26	0.32

← Traffic Flow   ← Traffic Flow

Westbound I-40 (Phase I)

Entire Bridge Crack Density: 0.38 m/m^2




37’
103’
37’
Crack Density for each Span (m/m2)
0.45
0.09
0.06
Traffic Flow
Control (4000psi)
HPC Cement Only + Fly Ash
+ Fibers
Traffic Flow
Eastbound I-40 (Phase II)
Entire Bridge Crack Density: 0.16 m/m2
37.3′
103.1′
37.3′
38.0′

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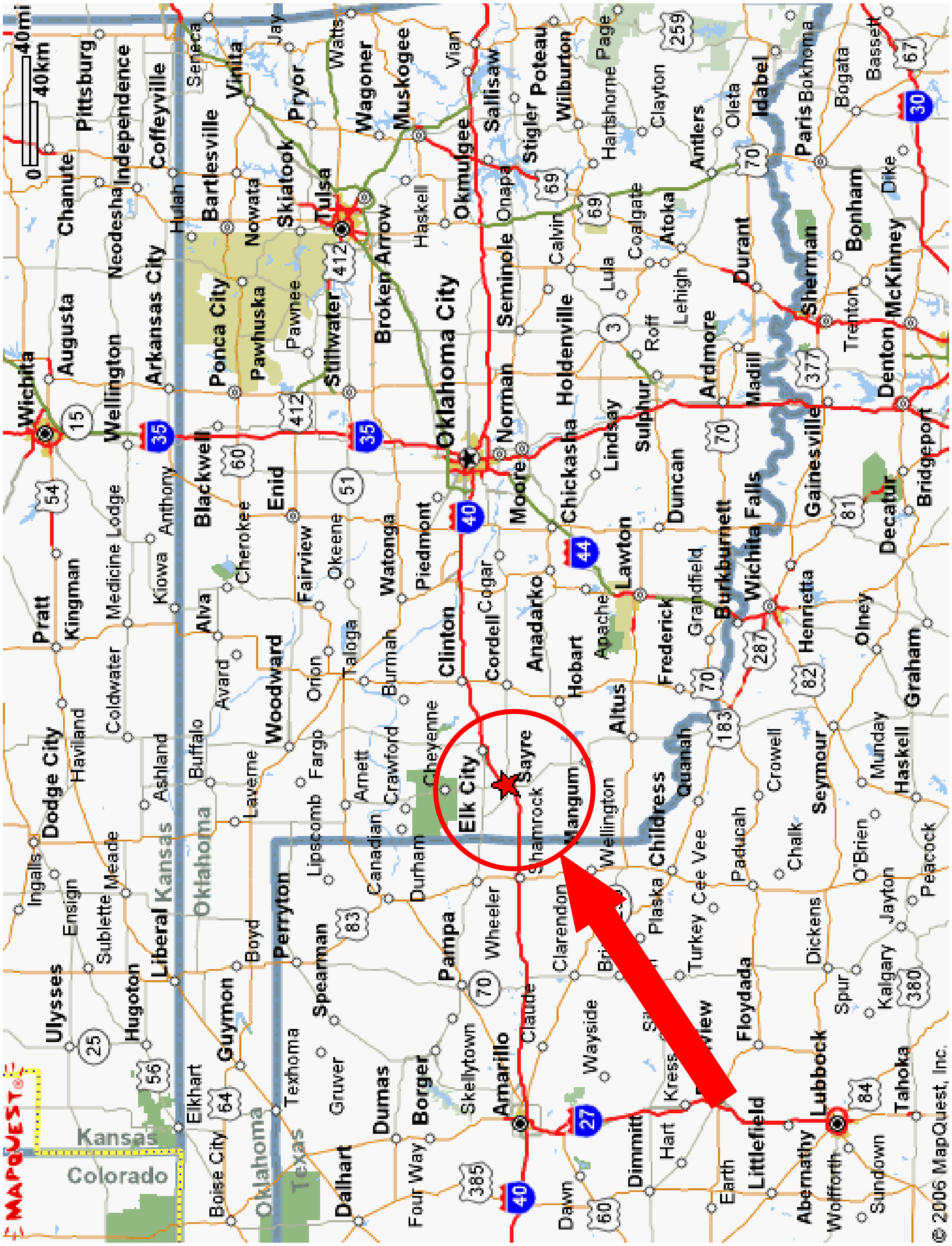
Appendix A -- Map

- Map of Oklahoma

(Image from (MapQuest, 2006))



Appendix B – Admixture Product Sheets

- Master Builders MB AE™ 90 Product Sheets
- Master Builders Polyheed® 1020 Product Sheets
- Master Builders Tetraguard® AS 20 Product Sheets

The Chemical Company

MB AE™ 90

Air-Entraining Admixture

Description

MB-AE 90 air-entraining admixture is for use in concrete mixtures. It meets the requirements of ASTM C 260, AASHTO M 154 and CRD-C 13.

Applications

Recommended for use in:

- Concrete exposed to cyclic freezing and thawing
- Production of high-quality normal or lightweight concrete (heavyweight concrete normally does not contain entrained air)

Features

- Ready-to-use in the proper concentration for rapid, accurate dispensing

Benefits

- Improved resistance to damage from cyclic freezing and thawing
- Improved resistance to scaling from deicing salts
- Improved plasticity and workability
- Reduced permeability – increased watertightness
- Reduced segregation and bleeding

Performance Characteristics

Concrete durability research has established that the best protection for concrete from the adverse effects of freezing and thawing cycles and deicing salts results from: proper air content in the hardened concrete, a suitable air-void system in terms of bubble size and spacing, and adequate concrete strength, assuming the use of sound aggregates and proper mixing, transporting, placing, consolidation, finishing and curing techniques. MB AE 90 admixture can be used to obtain adequate freeze-thaw durability in a properly proportioned concrete mixture, if standard industry practices are followed.

Air Content Determination: The total air content of normal weight concrete should be measured in strict accordance with ASTM C 231, “Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method” or ASTM C 173/C 173M, “Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method.” The air content of lightweight concrete should only be determined using the Volumetric Method. The air content should be verified by calculating the gravimetric air content in accordance with ASTM C 138/C 138M, “Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete.” If the total air content, as measured by the Pressure Method or Volumetric Method and as verified by the Gravimetric Method, deviates by more than 1-1/2%, the cause should be determined and corrected through equipment calibration or by whatever process is deemed necessary.

Product Data: MB AE™ 90

Guidelines for Use

Dosage: There is no standard dosage for MB AE 90 admixture. The exact quantity of air-entraining admixture needed for a given air content of concrete varies because of differences in concrete-making materials and ambient conditions. Typical factors that might influence the amount of air entrained include: temperature, cementitious materials, sand gradation, sand-aggregate ratio, mixture proportions, slump, means of conveying and placement, consolidation and finishing technique.

The amount of MB AE 90 admixture used will depend upon the amount of entrained air required under actual job conditions. In a trial mixture, use 1/4 to 4 fl oz/cwt (16-260 mL/100 kg) of cementitious material. Measure the air content of the trial mixture, and, if needed, either increase or decrease the quantity of MB AE 90 admixture to obtain the desired air content.

In mixtures containing water-reducing or set-control admixtures, the amount of MB AE 90 admixture needed may be somewhat less than the amount required in plain concrete.

Due to possible changes in the factors that can affect the dosage of MB AE 90 admixture, frequent air content checks should be made during the course of the work. Adjustments to the dosage should be based on the amount of entrained air required in the mixture at the point of placement.

If an unusually high or low dosage of MB AE 90 admixture is required to obtain the desired air content, consult your BASF Admixtures, Inc. representative. In such cases, it may be necessary to determine that, in addition to a proper air content in the fresh concrete, a suitable air-void system is achieved in the hardened concrete.

Dispensing & Mixing: Add MB AE 90 admixture to the concrete mixture using a dispenser designed for air-entraining admixtures, or add manually using a suitable measuring device that ensures accuracy within plus or minus 3% of the required amount.

For optimum, consistent performance, the air-entraining admixture should be dispensed on damp, fine aggregate. If the concrete mixture contains fine lightweight aggregate, field evaluations should be conducted to determine the best method to dispense the air-entraining admixture.

Product Notes

Compatibility: MB AE 90 admixture may be used in combination with any BASF Admixtures, Inc. admixture, unless stated otherwise on the data sheet for the other product. When used in conjunction with other admixtures, each admixture must be dispensed separately into the concrete mixture.

Storage and Handling

Storage Temperature: MB AE 90 admixture should be stored and dispensed at 31 °F (-0.5 °C) or higher. Although freezing does not harm this product, precautions should be taken to protect it from freezing. If MB AE 90 admixture freezes, thaw at 35 °F (2 °C) or above and completely reconstitute by mild mechanical agitation. ***Do not use pressurized air for agitation.***

Shelf Life: MB AE 90 admixture has a minimum shelf life of 12 months. Depending on storage conditions, the shelf life may be greater than stated. Please contact your BASF Admixtures, Inc. representative regarding suitability for use and dosage recommendations if the shelf life of MB AE 90 admixture has been exceeded.

Safety: Chemical goggles and gloves are recommended when transferring or handling this material.

Packaging

MB AE 90 admixture is supplied in 55 gal (208 L) drums, 275 gal (1040 L) totes and by bulk delivery.

Related Documents

Material Safety Data Sheets: MB AE 90 admixture.

Additional Information

For additional information on MB AE 90 admixture, or its use in developing a concrete mixture with special peformance characteristics, contact your BASF Admixtures, Inc. representative.

BASF Admixtures, Inc. is a leading provider of innovative chemical admixtures and silica fume for specialty concrete used in the ready mix, precast, manufactured concrete products, underground construction and paving markets in the United States and Canada. The Company's respected Master Builders brand products are used to improve the placing, pumping, finishing, appearance and performance characteristics of concrete.

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Master Builders

BASF

The Chemical Company

3	03 30 00 03 40 00 03 70 00	Product Data Cast-in-Place Concrete Precast Concrete Mass Concrete

POLYHEED® 1020

Mid-Range Water-Reducing Admixture

Description

PolyHeed 1020 admixture is a patent-pending ready-to-use mid-range water-reducing admixture. PolyHeed 1020 admixture, based on Glenium® technology, is very effective in producing concrete with different levels of workability for applications such as pumping and flatwork. PolyHeed 1020 admixture is also very effective in producing concrete with enhanced finishing characteristics. PolyHeed 1020 admixture meets ASTM C 494 requirements for Type A, water-reducing, and Type F, high-range water-reducing, admixtures.

Applications

Recommended for use in:

- Conventionally-placed concrete mixtures containing a wide range of cements, slag cement, Class C and F fly ashes, silica fume and manufactured sands
- Reinforced, precast, prestressed, light weight or normal-weight concrete and pumped concrete
- Residential/commercial flatwork and formed surfaces
- Concrete where 5 to 20% water reduction is desired
- Concrete where normal setting times are required
- Concrete where enhanced finishability is desired
- Concrete where flowability and increased durability are needed
- 4x4™ Concrete
- Pervious Concrete

Features

- Can be used in a wide variety of concrete mixtures as a multi-purpose admixturemeeting the performance requirements for ASTM Type A or Type F admixtures
- Dosage flexibility - provides up to 20% water reduction
- Reduced water content for a given level of workability
- Provides better slump retention
- Provides excellent workability of plastic concrete
- Enhanced later-age strength
- Excellent finishability, even with manufactured sands and in lean mixes

Benefits

- Faster setting at higher dosages compared to other mid-range water-reducing admixtures
- Enhanced concrete strength and durability
- Increased ease in finishing concrete
- Provides lower in-place cost
- Increases service life of structures

Performance Characteristics

Setting Time: Concrete produced with PolyHeed 1020 admixture sets faster than a mixture containing a typical mid-range water-reducing admixture.

Mixture Data: 517 lb/yd³ (307 kg/m³) of Type I/II cement; slump 5 in. (125 mm); non-air-entrained concrete; Admixture dosage adjusted for 8% water reduction.

Compressive Strength: Concrete produced with PolyHeed 1020 admixture achieves higher compressive strength at later ages compared to plain concrete and concrete mixtures produced with a typical mid-range water-reducing admixture.

Mixture Data: 517 lb/yd³ (307 kg/m³) of Type I/II cement; slump 5 in. (125mm); non-air entrained concrete; Admixture dosage adjusted for 12% water reduction.

Setting Time

Mixture	Initial set (h:min)	Difference (h:min)
Reference	4:48	–
Ref. Mid–Range Water–Reducer	6:12	+1:24
PolyHeed 1020 admixture	5:18	+0.30

Compressive Strength psi (MPa)

Mixture	1 Day	7–Day	28–Day
Plain	1330 (9.2)	3670 (25.3)	5080 (35.0)
Ref. Mid–Range Water–Reducer	1760 (12.1)	5160 (35.6)	6720 (46.3)
PolyHeed 1020 admixture	1940 (13.4)	5370 (37.0)	7150 (49.3)

Note: The data shown are based upon controlled laboratory tests. Reasonable variations from the results shown here may be experienced as a result of differences in concrete making materials and jobsite conditions.

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Product Data: POLYHEED® 1020

Guidelines for Use

Dosage: PolyHeed® 1020 admixture has a recommended dosage range of 3 to 12 fl oz/cwt (195 to 780 mL/100 kg) of cementitious materials for most concrete mixtures. A dosage range of 3 to 5 fl oz/cwt (195 to 325 mL/100 kg) is typical for Type A applications and up to 12 fl oz/cwt (780 mL/100 kg) for mid-range and high-range applications. Because of variations in concrete materials, job site conditions, and/or applications, dosages outside of the recommended range may be required. In such cases, contact your BASF Admixtures, Inc. representative.

Mixing: PolyHeed 1020 admixture can be added with the initial batch water or at the end of the batching sequence.

Product Notes

Corrosivity – Non-Chloride, Non-Corrosive: PolyHeed 1020 admixture will neither initiate nor promote corrosion of reinforcing or prestressing steel embedded in concrete, or of galvanized steel floor and roof systems. Neither calcium chloride nor other chloride-based ingredients are used in the manufacture of PolyHeed 1020 admixture. In all concrete applications, PolyHeed 1020 admixture conforms to the most stringent or minimum chloride ion limits currently suggested by construction industry standards and practices.

Compatibility: PolyHeed 1020 admixture is compatible with most admixtures and can be used in combination with other BASF Admixtures, Inc. admixtures, unless stated otherwise. When used in conjunction with other admixtures, each admixture must be dispensed separately into the concrete mixture.

PolyHeed 1020 admixture is designed to be used with MB-VR™ and MB-AE™ 90 air-entraining admixtures when the production of air-entrained concrete is desired. ***Do not use PolyHeed 1020 admixture in combination with naphthalene-based admixtures.*** Erratic performance in slump may be experienced.

Storage and Handling

Storage Temperature: PolyHeed 1020 admixture should be stored between 35 and 105 °F (2 and 41 °C). If PolyHeed 1020 admixture freezes, thaw at 40 °F (5 °C) or above and completely reconstitute using mild mechanical agitation. ***Do not use pressurized air for agitation.***

Shelf Life: PolyHeed 1020 admixture has a minimum shelf life of 12 months. Depending on storage conditions, the shelf life may be greater than stated. Please contact your BASF Admixtures, Inc. representative regarding suitability for use and dosage recommendations if the shelf life of PolyHeed 1020 admixture has been exceeded.

Dispensing: Consult your BASF Admixtures, Inc. representative for the proper dispensing equipment for PolyHeed 1020 admixture.

Packaging

PolyHeed 1020 admixture is supplied in 55 gal (208 L) drums, 275 gal (1040 L) totes, and by bulk delivery.

Related Documents

Material Safety Data Sheets: PolyHeed 1020 admixture

Additional Information

For additional information on PolyHeed 1020 admixture or its use in developing concrete mixtures with special performance characteristics, contact your BASF Admixtures, Inc. representative.

BASF Admixtures, Inc. is a leading provider of innovative chemical admixtures and silica fume for specialty concrete used in the ready mix, precast, manufactured concrete products, underground construction and paving markets in the United States and Canada. The Company's respected Master Builders brand products are used to improve the placing, pumping, finishing, appearance and performance characteristics of concrete.

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BASF The Chemical Company

TETRAGUARD® AS20

Shrinkage-Reducing Admixture

Description

Tetraguard AS20 shrinkage-reducing admixture is the first commercially available chemical admixture developed specifically to reduce drying shrinkage of concrete and mortar, and the potential for subsequent cracking. Tetraguard AS20 admixture has been used successfully in the Far East and North American construction markets since its introduction in 1985.

Tetraguard AS20 admixture was developed to replace/enhance inorganic expansive admixtures that were being used to prevent drying shrinkage cracking. These expansive admixtures acted by inducing compressive stresses in concrete to offset tensile stresses caused by drying shrinkage.

Tetraguard AS20 admixture functions by reducing capillary tension of pore water, a primary cause of drying shrinkage.

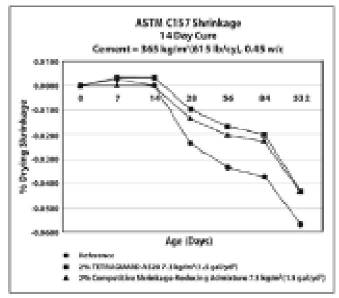
Applications

Recommended for use in:

- Ready mix or precast concrete structures requiring shrinkage reduction and long term durability
- Wet mix shotcrete
- Mortars and grouts

Features

- Significantly reduces drying shrinkage by as much as 80% at 28 days, and up to 50% at one year or beyond when 2% Tetraguard AS20 admixture by mass of cement is used in the concrete mixture
- Reduces stresses induced from one-dimensional surface drying in concrete slabs and floors
- Reduces compressive creep
- Reduces carbonation



Benefits

- Reduces drying shrinkage cracking and microcracking thereby improving aesthetics, watertightness and durability
- Reduces compressive creep under drying conditions that minimizes prestress loss
- Minimizes curling

Performance Characteristics

Tetraguard AS20 admixture does not substantially affect slump. Tetraguard AS20 admixture may increase bleed time and bleed ratio (10% higher). Tetraguard AS20 admixture may also delay time of set by 1-2 hours depending upon dosage and temperature. Compressive strength loss is minimal with Tetraguard AS20 admixture.

All projects requiring Tetraguard AS20 admixture in concrete applications exposed to freezing and thawing environments must be pre-approved and require field trails prior to use. Therefore, contact a BASF Admixtures, Inc. representative when concrete treated with Tetraguard AS20 admixture is being proposed for applications exposed to freezing and thawing environments.

Guidelines for Use

Dosage: The dosage of Tetraguard AS20 admixture will be dependent on the reduction of drying shrinkage required. Knowledge of the shrinkage characteristics of the concrete mixture proposed for use is required prior to the addition of Tetraguard AS20 admixture.

The typical dosage range of Tetraguard AS20 admixture is 0.5 to 1.5 gal/yd^3 (2.5-7.5 L/m^3). However, dosages outside of this range may be required depending on the level of shrinkage reduction needed.

Master Builders

Product Data: TETRAGUARD® AS20

Mixing: Tetraguard AS20 admixture may be added to the concrete mixture during the initial batch sequence or at the jobsite.

The mix water content should be reduced to account for the quantity of Tetraguard AS20 admixture used.

If the delayed addition method is used, mixing at high speed for 3-5 minutes after the addition of Tetraguard AS20 admixture will result in mixture uniformity.

Product Notes

Corrosivity – Non-Chloride, Non-Corrosive: Tetraguard AS20 admixture will neither initiate nor promote corrosion of reinforcing steel, prestressing steel or of galvanized steel floor and roof systems. Neither calcium chloride nor other chloride-based ingredients are used in the manufacture of Tetraguard AS20 admixture.

Compatibility: Tetraguard AS20 admixture is compatible with all water reducers, mid-range water-reducers, superplasticizers, set retarders, accelerators, silica fume, and corrosion inhibitors. For air-entrained concrete applications, Micro-Air® admixture is the recommended air-entrainer. Tetraguard AS20 admixture should be added separately to the concrete mixture to ensure desired results.

Storage and Handling

Storage Temperature: Tetraguard AS20 admixture is a potentially combustible material with a flash point of 208 °F (98 °C). This is substantially above the upper limit of 140 °F (60 °C) for classification as a flammable material, and above the limit of 200 °F (93 °C) where DOT requirements would classify this as a combustible material. Nonetheless, this product must be treated with care and protected from excessive heat, open flame or sparks. For more information consult the MSDS.

Tetraguard AS20 admixture should be stored at ambient temperatures above 35 °F (2 °C), and precautions should be taken to protect the admixture from freezing. If Tetraguard AS20 admixture freezes, thaw and reconstitute by mild mechanical agitation. ***Do not use pressurized air for agitation.***

Shelf Life: Tetraguard AS20 admixture has a minimum shelf life of 12 months. Depending on storage conditions, the shelf life may be greater than stated. Please contact your BASF Admixtures, Inc. representative regarding suitability for use and dosage recommendations if the shelf life of Tetraguard AS20 admixture has been exceeded.

Packaging

Tetraguard AS20 admixture is available in 55 gal (208 L) drums and 268 gal (1014 L) totes.

Related Documents

Material Safety Data Sheets: Tetraguard AS20 admixture.

Additional Information

For additional information on Tetraguard AS20 admixture or its use in developing concrete mixtures with special performance characteristics, contact your BASF Admixtures, Inc. representative.

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Appendix C – Batch Data Sheets

- Laboratory Data Sheets
- Test Slab Data Sheets
- Bridge Construction Data Sheets

Batch # **1** DATE: N/A

D.R.U.W.	127	#/c.f.
Air Temp.	81.25	°F
Rel. Hum.	54.5	%
Conc. Temp.	80.75	°F
Slump	4.5	in.
Unit Wt.	139.65	#/c.f.
Air Content	9.0	%

M.C.

	CA	***IA***	***FA***
P	N/A	N/A	N/A
W+P	N/A	N/A	N/A
D+P	N/A	N/A	N/A
%	N/A	N/A	N/A

Compression:

Days	avg. psi	avg. MPa.
0	0	0
1	1680	12
3	3048	21
28	3416	24
56	3390	23

Shrinkage:

Days	avg. % Microstrain
0	0
1	0
3	-162
10	-313
14	-402
21	-431
28	-470
56	-518

Modulus of Elasticity:

	psi
E=	2,911,858
	MPa
	20,082

Workability:

Notes:

Batch #	2		DATE:	6/1/2005
D.R.U.W.	127	#/c.f.		
Air Temp.	81	°F		
Rel. Hum.	55	%		
Conc. Temp.	81	°F		
Slump	5.75	in.		
Unit Wt.	129.1	#/c.f.		
Air Content	14	%		

M.C.

	CA	*IA*	*FA*
P	1.13	-	1.4
W+P	9.31	-	8.37
D+P	N/R	-	N/R
%	---	---	---

Compression:

Days	psi	fracture style
1	565	cone & shear
	568	cone & shear
	549	columnar
3	1323	cone
	1268	cone
	1343	cone
28	1303	cond & shear
	1334	cone & shear
	1232	cone & shear
56	1243	cone & shear
	1490	cone & shear
	1366	cone & shear

Days	avg. psi	avg. MPa.
0	0	0
1	561	4
3	1311	9
28	1290	9
56	1366	9

Shrinkage:

Days	a) +1200		b) +1200		c) +1300		avg. % Microstrain
0	0		0		0		0
1	82	0	45	0	97	0	0
3	68	-140	30	-150	82	-150	-147
7	53	-290	14	-310	65	-320	-307
14	46	-360	5	-400	60	-370	-377
21	45	-370	3	-420	58	-390	-393
28	43	-390	2	-430	56	-410	-410
56	39	-430	96	-490	51	-460	-460

Modulus of Elasticity:

$0.4\,f'_c =$ 529.2

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{\text{each test}}$	$E_{\text{each spec.}}$
1)	127	276	1,779,646	1,885,323
1)	131	250	1,991,000	
2)	124	295	1,653,878	1,659,339
2)	113	300	1,664,800	

E= psi 1,772,331

MPa 12,223

Workability:

doughy, very flowing

Batch #	3			DATE:	5/30/2005

D.R.U.W.	126	#/c.f.
Air Temp.	70	°F
Rel. Hum.	74	%
Conc. Temp.	N/R	°F
Slump	4.25	in.
Unit Wt.	136.3	#/c.f.
Air Content	10.5	%

M.C.

	CA	*IA*	*FA*
P	1.4	1.13	0.55
W+P	15.58	10.6	6.63
D+P	15.57	10.59	6.56
%	0.07	0.11	1.16
		(3/8 chip)	

Compression:

Days	psi	fracture style
1	1358	cone
	1666	columnar
	1308	cone & shear
3	2640	shear
	2344	cone & shear
	2558	cone & shear
28	2016	cone & shear
	2765	shear
	2612	shear
56	2527	cone & shear
	2284	cone & shear
	2578	cone & shear

Days	avg. psi	avg. MPa.
0	0	0
1	1444	10
3	2514	17
28	2464	17
56	2463	17

Shrinkage:

Days	a) +800		b) +800		c) +600		avg. % Microstrain
0	0		0		0		0
1	52	0	90	0	9	0	0
3	44	-80	80	-100	99	-100	-93
7	34	-180	68	-220	87	-220	-207
14	25	-270	57	-330	79	-300	-300
21	24	-280	56	-340	78	-310	-310
28	21	-310	53	-370	76	-330	-337
56	20	-320	50	-400	76	-330	-350

Modulus of Elasticity:

$0.4\ f'_c =$ 985.7

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	158	384	2,478,144	2,450,395
1)	162	390	2,422,647	
2)	error	error	error	error
2)	error	error	error	

E= psi 2,450,395

MPa 16,899

Workability:
good

Batch # **4** DATE: 5/31/2005

D.R.U.W.	126	#/c.f.	M.C.				
Air Temp.	75	°F			**CA**	**IA**	**FA**
Rel. Hum.	68	%		P	1.13	0.55	1.4
Conc. Temp.	78	°F		W+P	7.37	3.37	6.85
Slump	1.75	in.		D+P	7.37	3.36	6.79
Unit Wt.	153.2	#/c.f.		%	0.00	0.36	1.11
Air Content	1.9	%				(3/8 chip)	

Compression:

Days	psi	fracture style
1	2061	cone
	2241	shear
	2157	cone & shear
3	5012	shear
	4770	columnar
	4921	cone & split
28	5866	cone & shear
	5653	cone & shear
	5335	cone & shear
56	5838	cone & shear
	5816	cone & shear
	5800	shear

Days	avg. psi	avg. MPa.
0	0	0
1	2153	15
3	4901	34
28	5618	39
56	5818	40

Shrinkage:

Days	a) +500		b) +300		c) +200		avg. % Microstrain
0	0		0		0		0
1	93	0	35	0	25	0	0
3	84	-90	28	-70	18	-70	-77
7	78	-150	23	-120	12	-130	-133
14	70	-230	16	-190	5	-200	-207
21	68	-250	15	-200	4	-210	-220
28	68	-250	14	-210	3	-220	-227
56	64	-290	10	-250	0	-250	-263

Modulus of Elasticity:

$0.4\ f'_c=$ 2247.2

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{\text{each test}}$	$E_{\text{each spec.}}$
1)	264	522	4,201,695	4,212,525
1)	258	521	4,223,355	
2)	285	474	4,627,830	4,638,381
2)	290	471	4,648,931	

E= 4,425,453 psi

30,520 MPa

Workability:
rocky but very workable

Batch #	5			DATE:	6/8/2005

D.R.U.W.	126	#/c.f.
Air Temp.	91	°F
Rel. Hum.	58	%
Conc. Temp.	82	°F
Slump	4	in.
Unit Wt.	132	#/c.f.
Air Content	13.5	%

M.C.

	CA	*IA*	*FA*
P	0.55	1.4	0.47
W+P	3.2	4.45	2.54
D+P	3.2	4.44	2.53
%	0.00	0.33	0.49
		(3/8 chip)	

Compression:

Days	psi	fracture style
1	608	cone & shear
	770	columnar
	656	cone & shear
4	1553	columnar
	1453	cone & split
	1642	cone
28	1251	cone
	1256	cone
	1370	shear
56	1241	cone & shear
	1536	cone & shear
	1498	cone & shear

Days	avg. psi	avg. MPa.
0	0	0
1	678	5
4	1549	11
28	1292	9
56	1425	10

Shrinkage:

Days	a) +200		b) +1200		c) +1700		avg. % Microstrain
0	0		0		0		0
1	7	0	18	0	32	0	0
4	86	-210	5	-130	14	-180	-173
7	77	-300	94	-240	3	-290	-277
14	67	-400	89	-290	97	-350	-347
21	62	-450	85	-330	94	-380	-387
28	55	-520	80	-380	89	-430	-443
56	55	-520	81	-370	89	-430	-440

Modulus of Elasticity:

$0.4\ f'_c$= 516.9

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	89	315	1,614,717	1,635,351
1)	88	309	1,655,985	
2)	154	254	1,778,922	1,740,640
2)	156	262	1,702,358	

E= 1,687,995 psi

11,641 MPa

Workability:

real workable

Batch # **6** DATE: 6/8/2005

D.R.U.W.	126.00	#/c.f.
Air Temp.	91	°F
Rel. Hum.	57	%
Conc. Temp.	84	°F
Slump	1.75	in.
Unit Wt.	144.8	#/c.f.
Air Content	7.2	%

M.C.

	CA	*IA*	*FA*
P	0.55	1.4	0.47
W+P	3.2	4.45	2.54
D+P	3.2	4.44	2.53
%	0.00	0.33	0.49
		(3/8 chip)	

Compression:

Days	psi	fracture style
1	1477	cone & shear
	1499	cone & shear
	1550	cone & shear
4	3239	cone
	3269	cone & split
	3154	shear
28	3326	cone
	3248	cone & split
	3256	cone
56	3221	cone & split
	3474	cone & split
	3232	cone & shear

Days	avg. psi	avg. MPa.
0	0	0
1	1509	10
4	3221	22
28	3277	23
56	3309	23

Shrinkage:

Days	a) +1600		b) +2100		c) +1500		avg. % Microstrain
0	0		0		0		0
1	75	0	26	0	27	0	0
4	66	-90	18	-80	18	-90	-87
7	59	-160	12	-140	9	-180	-160
14	54	-210	8	-180	5	-220	-203
21	52	-230	4	-220	3	-240	-230
28	48	-270	0	-260	0	-270	-267
56	47	-280	0	-260	99	-280	-273

Modulus of Elasticity:

$0.4\ f'_c =$ 1310.7

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{\text{each test}}$	$E_{\text{each spec.}}$
1)	296	336	3,547,902	3,595,354
1)	298	328	3,642,806	
2)	271	346	3,512,500	3,550,164
2)	220	354	3,587,829	

E= 3,572,759 psi

24,640 MPa

Workability:
little rocky

Batch #	**7**					DATE:	6/8/2005
D.R.U.W.	126	#/c.f.	M.C.				
Air Temp.	90	^oF		CA	IA	FA	
Rel. Hum.	59	%	P	0.55	1.4	0.47	
Conc. Temp.	84	^oF	W+P	3.2	4.45	2.54	
Slump	1.25	in.	D+P	3.2	4.44	2.53	
Unit Wt.	146	#/c.f.	%	0.00	0.33	0.49	
Air Content	6.4	%			(3/8 chip)		

Compression:

Days	psi	fracture style
1	1579	cone & shear
	1662	shear
	1713	cone & shear
4	3700	cone
	3457	columnar
	3659	columnar
28	3965	chip
	3963	chip
	4197	chip
56	3930	cone & split
	3651	columnar
	3743	cone & shear

Days	avg. psi	avg. MPa.
0	0	0
1	1651	11
4	3605	25
28	4042	28
56	3775	26

Shrinkage:

Days	a) +1500		b) +1500		c) +1400		avg. % Microstrain
0	0		0		0		0
1	97	0	44	0	11	0	0
4	89	-80	12	-320	3	-80	-80
7	83	-140	7	-370	98	-130	-135
14	77	-200	1	-430	92	-190	-195
21	75	-220	99	-450	90	-210	-215
28	70	-270	95	-490	86	-250	-260
56	71	-260	96	-480	87	-240	-250

Modulus of Elasticity:

$0.4 f'_c =$ 1616.7

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	255	412	3,761,602	3,761,602
1)	255	412	3,761,602	
2)	213	448	3,526,884	3,533,166
2)	208	448	3,539,447	

E= psi: 3,647,384

MPa: 25,154

Workability:

N/R

Batch # **8** DATE: 6/16/2005

D.R.U.W.	129.56	#/c.f.
Air Temp.	87	°F
Rel. Hum.	60	%
Conc. Temp.	81	°F
Slump	2	in.
Unit Wt.	144.5	#/c.f.
Air Content	7.2	%

M.C.

	CA	*IA*	*FA*
P	0.55	1.13	0.47
W+P	7.42	8.1	5.93
D+P	7.42	8.09	5.9
%	0.00	0.14	0.55
		(medium)	

Compression:

Days	psi	fracture style
1	1211	columnar
	1323	cone & shear
	1122	columnar
3	3285	shear
	3339	columnar
	3423	shear
28	4135	cone & shear
	3786	cone & shear
	4084	cone & split
56	3632	crushed
	3484	shear/columnar
	3576	shear/columnar

Days	avg. psi	avg. MPa.
0	0	0
1	1219	8
3	3349	23
28	4002	28
56	3564	25

Shrinkage:

Days	a) +1200		b) +1400		c) +1500		avg. % Microstrain
0	0		0		0		0
1	4	0	90	0	24	0	0
3	97	-70	82	-80	16	-80	-77
7	89	-150	75	-150	9	-150	-150
14	82	-220	69	-210	4	-200	-210
21	80	-240	67	-230	1	-230	-233
28	68	-360	66	-240	99	-250	-283
56	66	-380	65	-250	98	-260	-297

Modulus of Elasticity:

$0.4\ f'_c =$ 1600.7

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	242	439	3,492,802	3,505,125
1)	250	434	3,517,448	
2)	204	437	3,609,044	3,637,462
2)	204	431	3,665,879	

E= 3,571,293 psi

24,630 MPa

Workability:

Rocky but flowy, easy finish

Batch # **9** DATE: 6/16/2005

D.R.U.W.	123.92	#/c.f.
Air Temp.	88	°F
Rel. Hum.	60	%
Conc. Temp.	80	°F
Slump	2.5	in.
Unit Wt.	135.6	#/c.f.
Air Content	11	%

M.C.

	CA	*IA*	*FA*
P	0.55	1.4	0.47
W+P	7.42	7.35	5.93
D+P	7.42	7.35	5.9
%	0.00	0.00	0.55
		(3/8 chip)	

Compression:

Days	psi	fracture style
1	909	cone & shear
	848	cone & shear
	894	cone & shear
3	2053	shear
	2153	columnar
	2233	N/R
28	2375	cone & shear
	2355	cone & shear
	2346	cone & shear
56	2316	cone & shear
	2449	cone & shear
	2303	cone & shear

Days	avg. psi	avg. MPa.
0	0	0
1	884	6
3	2146	15
28	2359	16
56	2356	16

Shrinkage:

Days	a) +1400		b) +1500		c) +1600		avg. % Microstrain
0	0		0		0		0
1	72	0	69	0	79	0	0
3	61	-110	56	-130	61	-180	-140
7	49	-230	46	-230	51	-280	-247
14	43	-290	35	-340	42	-370	-333
21	38	-340	30	-390	38	-410	-380
28	35	-370	28	-410	38	-410	-397
56	33	-390	24	-450	33	-460	-433

Modulus of Elasticity:

$0.4\ f'_c=$ 943.5

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	143	385	2,389,552	2,359,230
1)	154	389	2,328,909	
2)	167	347	2,614,478	2,579,298
2)	165	356	2,544,118	

E= **psi** 2,469,264

MPa 17,029

Workability:
very nice, easy finish

Batch #	**10**					DATE:	6/17/2005
D.R.U.W.	122.88	#/c.f.	M.C.				
Air Temp.	81	°F		*CA*	*IA*	*FA*	
Rel. Hum.	55	%	P	0.55	1.4	0.47	
Conc. Temp.	77	°F	W+P	7.42	7.35	5.93	
Slump	4	in.	D+P	7.42	7.35	5.9	
Unit Wt.	149.9	#/c.f.	%	0.00	0.00	0.55	
Air Content	4.5	%			(3/8 chip)		

Compression:

Days	psi	fracture style
1	2580	cone
	2683	cone
	2558	cone
3	3987	shear
	4533	shear
	4062	cone & shear
28	5438	shear
	5507	shear
	5201	cone & split
56	4205	shear
	4555	chip
	5080	shear

Days	avg. psi	avg. MPa.
0	0	0
1	2607	18
3	4194	29
28	5382	37
56	4613	32

Shrinkage:

Days	a) +600		b) +1400		c) +1800		avg. % Microstrain
0	0		0		0		0
1	47	0	82	0	36	0	0
3	42	-50	77	-50	31	-50	-50
7	35	-120	70	-120	23	-130	-123
14	29	-180	63	-190	17	-190	-187
21	27	-200	60	-220	14	-220	-213
28	26	-210	61	-210	14	-220	-213
56	25	-220	59	-230	10	-260	-237

Modulus of Elasticity:

$0.4\ f'_c =$ 2152.8

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	221	553	3,840,557	3,845,378
1)	220	552	3,850,199	
2)	231	521	4,080,255	4,086,723
2)	229	520	4,093,191	

E= **psi** 3,966,051

MPa 27,352

Workability:
rocky with very soupy mortar

Batch # **11**

DATE: 6/20/2005

D.R.U.W.	129.88	#/c.f.
Air Temp.	88	°F
Rel. Hum.	42	%
Conc. Temp.	84	°F
Slump	0.75	in.
Unit Wt.	145.5	#/c.f.
Air Content	6.4	%

M.C.

	CA	*IA*	*FA*
P	1.41	0.55	0.47
W+P	11.08	5.16	5.68
D+P	11.07	5.16	5.62
%	0.10	0.00	1.17
		(medium)	

Compression:

Days	psi	fracture style
1	1117	cone & shear
	1475	cone & shear
	1391	cone & shear
3	2873	cone & shear
	2803	shear
	2806	shear
28	3509	shear
	3570	shear
	3156	N/R
56	3118	cone & shear
	3439	cone & shear
	3578	cone & shear

Days	avg. psi	avg. MPa.
0	0	0
1	1328	9
3	2827	19
28	3412	24
56	3378	23

Shrinkage:

Days	a) +1400		b) +1500		c) +1000		avg. % Microstrain
0	0		0		0		0
1	22	0	12	0	12	0	0
3	9	-130	6	-60	3	-90	-93
7	1	-210	96	-160	94	-180	-183
14	92	-300	89	-230	85	-270	-267
21	91	-310	88	-240	84	-280	-277
28	90	-320	86	-260	82	-300	-293
56	89	-330	86	-260	82	-300	-297

Modulus of Elasticity:

$0.4\ f'_c=$ 1364.7

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	188	429	3,104,749	3,096,717
1)	191	430	3,088,684	
2)	228	404	3,211,017	3,106,420
2)	212	434	3,001,823	

E= **psi** 3,101,568 **MPa** 21,390

Workability:
sticky, kind of rocky, hard to finish

Batch # **12**

DATE: 6/20/2005

D.R.U.W.	124.52	#/c.f.
Air Temp.	87	°F
Rel. Hum.	39	%
Conc. Temp.	80	°F
Slump	1	in.
Unit Wt.	144.6	#/c.f.
Air Content	7	%

M.C.

	CA	*IA*	*FA*
P	1.41	0.55	0.47
W+P	11.08	5.16	5.68
D+P	11.07	5.16	5.62
%	0.10	0.00	1.17
		(medium)	

Compression:

Days	psi	fracture style
1	1354	cone & shear
	1676	columnar
	1684	cone & shear
3	3105	shear
	2998	cone & shear
	3132	cone & shear
28	3782	cone & shear
	3804	cone & split
	3723	cone & shear
56	3789	cone & split
	3285	cone & shear
	3587	cone & split

Days	avg. psi	avg. MPa.
0	0	0
1	1571	11
3	3078	21
28	3770	26
56	3554	25

Shrinkage:

Days	a) +1300		b) +1400		c) +1400		avg. % Microstrain
0	0		0		0		0
1	8	0	77	0	1	0	0
3	98	-100	69	-80	92	-90	-90
7	92	-160	61	-160	86	-150	-157
14	83	-250	52	-250	76	-250	-250
21	82	-260	50	-270	73	-280	-270
28	78	-300	46	-310	67	-340	-317
56	77	-310	47	-300	67	-340	-317

Modulus of Elasticity:

$0.4\ f'_c =$ 1501.2

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	220	460	3,124,878	3,100,591
1)	203	472	3,076,303	
2)	191	437	3,385,530	3,368,212
2)	191	441	3,350,895	

E= 3,234,402 psi

22,306 MPa

Workability:

dry, not greatest workability, semi-easy finishing

Batch #	13			DATE:	6/22/2005

D.R.U.W.	126.76	#/c.f.
Air Temp.	91	°F
Rel. Hum.	39	%
Conc. Temp.	82	°F
Slump	0.5	in.
Unit Wt.	147.6	#/c.f.
Air Content	4.7	%

M.C.

	CA	*IA*	*FA*
P	1.13	0.39	0.55
W+P	9.33	5.87	5.93
D+P	9.32	5.86	5.87
%	0.12	0.18	1.13
		(3/8 chip)	

Compression:

Days	psi	fracture style
1	1797	cone & split
	1929	cone & shear
	1861	cone & shear
3	3153	cone & split
	3627	cone
	3291	N/R
28	3877	cone & shear
	4700	cone & split
	4636	cone & shear
56	4520	cone & shear
	4407	cone & shear
	4347	cone & shear

Days	avg. psi	avg. MPa.
0	0	0
1	1862	13
3	3357	23
28	4404	30
56	4425	31

Shrinkage:

Days	a) +1500		b) +1000		c) +1300		avg. % Microstrain
0	0		0		0		0
1	5	0	52	0	64	0	0
3	99	-60	47	-50	57	-70	-60
8	87	-180	34	-180	36	-280	-213
14	81	-240	36	-160	29	-350	-250
21	78	-270	16	-360	24	-400	-343
28	77	-280	14	-380	27	-370	-343
56	76	-290	13	-390	25	-390	-357

Modulus of Elasticity:

0.4 f'_c= 1761.7

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	269	478	3,487,617	3,492,297
1)	258	480	3,496,977	
2)	261	422	4,034,140	4,024,630
2)	248	427	4,015,119	

E= 3,758,463 psi

25,920 MPa

Workability:
rocky, very dry

Batch #	14			DATE: 6/23/2005

D.R.U.W.	122.92	#/c.f.
Air Temp.	91	°F
Rel. Hum.	39	%
Conc. Temp.	86	°F
Slump	1.5	in.
Unit Wt.	145.6	#/c.f.
Air Content	5.8	%

M.C.

	CA	*IA*	*FA*
P	0.55	1.13	0.47
W+P	5.07	5.3	4.79
D+P	5.06	5.29	4.76
%	0.22	0.24	0.70
		(3/8 chip)	

Compression:

Days	psi	fracture style
1	1819	shear
	1760	shear
	1741	shear
3	3468	cone
	3745	cone
	3570	cone
28	4027	cone & shear
	4229	cone & shear
	4192	cone & shear
56	4003	cone & shear
	4043	columnar
	4028	columnar

Days	avg. psi	avg. MPa.
0	0	0
1	1773	12
3	3594	25
28	4149	29
56	4025	28

Shrinkage:

Days	a) +1700		b) +1400		c) +1600		avg. % Microstrain
0	0		0		0		0
1	91	0	9	0	87	0	0
3	83	-80	2	-70	72	-150	-100
7	65	-260	90	-190	59	-280	-243
14	58	-330	83	-260	51	-360	-317
21	56	-350	81	-280	49	-380	-337
28	54	-370	80	-290	49	-380	-347
56	52	-390	81	-280	48	-390	-353

Modulus of Elasticity:

$0.4\ f'_c=$ 1659.7

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{\text{each test}}$	$E_{\text{each spec.}}$
1)	228	489	3,261,276	3,286,181
1)	226	483	3,311,085	
2)	232	510	3,103,696	3,193,231
2)	212	491	3,282,766	

E=	
psi	3,239,706
MPa	22,343

Workability:

nice, easy to finish

Batch #	15					DATE:	N/A

				M.C.			
D.R.U.W.	123.24	#/c.f.			***CA***	***IA***	***FA***
Air Temp.	92	°F		P	N/A	N/A	N/A
Rel. Hum.	40.5	%		W+P	N/A	N/A	N/A
Conc. Temp.	88	°F		D+P	N/A	N/A	N/A
Slump	1.125	in.		%	N/A	N/A	N/A
Unit Wt.	147.7	#/c.f.				(3/8 chip)	
Air Content	5.05	%					

Compression:

Days	avg. psi	avg. MPa.
0	0	0
1	2291	16
3	4220	29
28	5022	35
56	4839	33

Shrinkage:

Days	avg. % Microstrain
0	0
1	0
3	-93
7	-210
14	-268
21	-285
28	-315
56	-333

Modulus of Elasticity:

	psi
E=	3,805,556
	MPa
	26,245

Workability:

Batch # **16**

DATE: N/A

D.R.U.W.	123.2	#/c.f.
Air Temp.	96	^oF
Rel. Hum.	35	%
Conc. Temp.	87.5	^oF
Slump	2.875	in.
Unit Wt.	137.6	#/c.f.
Air Content	9.3	%

M.C.

	CA	*IA*	*FA*
P	N/A	N/A	N/A
W+P	N/A	N/A	N/A
D+P	N/A	N/A	N/A
%	N/A	N/A	N/A
		(3/8 chip)	

Compression:

Days	avg. psi	avg. MPa.
0	0	0
1	1155	8
7	2175	15
28	2604	18
56	2495	17

Shrinkage:

Days	avg. % Microstrain
0	0
1	0
3	-152
7	-312
14	-387
21	-423
28	-415
56	-435

Modulus of Elasticity:

	psi
E=	2,624,290
	MPa
	18,099

Workability:

Batch #	17		
D.R.U.W.	123.2	#/c.f.	
Air Temp.	93	°F	
Rel. Hum.	39	%	
Conc. Temp.	88	°F	
Slump	2.25	in.	
Unit Wt.	134.4	#/c.f.	
Air Content	11.5	%	

DATE: 6/29/2005

M.C.

	CA	*IA*	*FA*
P	1.4	0.39	1.13
W+P	6.38	4.65	5.7
D+P	6.38	4.65	5.64
%	0.00	0.00	1.33
		(3/8 chip)	

Compression:

Days	psi	fracture style
1	1050	cone
	1227	cone
	1050	shear
7	2303	cone & split
	2408	columnar
	2036	shear
28	2160	cone & shear
	2360	columnar
	2176	cone & shear
56	2010	chip
	2004	shear
	2053	shear

Days	avg. psi	avg. MPa.
0	0	0
1	1109	8
7	2249	16
28	2232	15
56	2022	14

Shrinkage:

Days	a) +1400		b) +1200		c) +1500		avg. % Microstrain
0	0		0		0		0
1	24	0	39	0	66	0	0
3	N/R	N/R	N/R	N/R	N/R	N/R	N/R
7	0	-240	16	-230	43	-230	-233
14	94	-300	7	-320	35	-310	-310
21	93	-310	7	-320	34	-320	-317
28	93	-310	1	-380	28	-380	-357
56	92	-320	99	-400	26	-400	-373

Modulus of Elasticity:

$0.4\ f'_c=$ 892.8

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	181	358	2,311,039	2,323,493
1)	178	356	2,335,948	
2)	134	384	2,271,856	2,266,973
2)	135	385	2,262,090	

E= 2,295,233 psi

15,829 MPa

Workability:

excellent, pretty easy finish

Batch # **18** DATE: 6/30/2005

D.R.U.W.	123.2	#/c.f.
Air Temp.	91	°F
Rel. Hum.	40	%
Conc. Temp.	84	°F
Slump	1	in.
Unit Wt.	150.2	#/c.f.
Air Content	4.6	%

M.C.

	CA	*IA*	*FA*
P	0.34	0.39	0.55
W+P	3.26	2.84	3.44
D+P	3.25	2.83	3.42
%	0.34	0.41	0.70
		(3/8 chip)	

Compression:

Days	psi	fracture style
1	1337	N/R
	1248	N/R
	1369	N/R
3	4116	chip
	3993	chip
	3976	N/R
28	5609	shear
	5547	cone & shear
	6123	cone & split
56	6347	chip
	5761	chip
	5597	chip

Days	avg. psi	avg. MPa.
0	0	0
1	1318	9
3	4028	28
28	5760	40
56	5902	41

Shrinkage:

Days	a) +1400		b) +1000		c) +1600		avg. % Microstrain
0	0		0		0		0
1	83	0	49	0	71	0	0
3	77	-60	38	-110	65	-60	-77
7	70	-130	30	-190	59	-120	-147
14	66	-170	26	-230	53	-180	-193
21	62	-210	22	-270	48	-230	-237
28	64	-190	20	-290	47	-240	-240
56	61	-220	18	-310	45	-260	-263

Modulus of Elasticity:

$0.4\ f'_c=$ 2303.9

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	263	548	4,098,126	4,101,243
1)	264	547	4,104,359	
2)	285	513	4,360,403	4,378,983
2)	259	515	4,397,563	

E= **psi** 4,240,113 **Mpa** 29,242

Workability:
pretty workable, better

Batch # **19** DATE: 6/30/2005

D.R.U.W.	123.2	#/c.f.
Air Temp.	92	°F
Rel. Hum.	38	%
Conc. Temp.	84	°F
Slump	5.5	in.
Unit Wt.	137.8	#/c.f.
Air Content	9.75	%

M.C.

	CA	*IA*	*FA*
P	0.34	0.39	0.55
W+P	3.26	2.84	3.44
D+P	3.25	2.83	3.42
%	0.34	0.41	0.70
		(3/8 chip)	

Compression:

Days	psi	fracture style
1	382	N/R
	266	N/R
	358	N/R
3	1571	shear
	1697	shear
	1566	shear
28	2185	cone & shear
	2096	cone & shear
	1913	cone & shear
56	2069	chip
	1859	chip
	2087	chip

Days	avg. psi	avg. MPa.
0	0	0
1	335	2
3	1611	11
28	2065	14
56	2005	14

Shrinkage:

Days	a) +1400		b) +1200		c) +1400		avg. % Microstrain
0	0		0		0		0
1	48	0	92	0	4	0	0
3	40	-80	88	-40	92	-120	-80
7	33	-150	75	-170	80	-240	-187
14	12	-360	69	-230	59	-450	-347
21	11	-370	69	-230	57	-470	-357
28	12	-360	70	-220	60	-440	-340
56	10	-380	68	-240	58	-460	-360

Modulus of Elasticity:

$0.4\ f'_c=$ 825.9

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	172	330	2,335,238	2,329,881
1)	175	330	2,324,524	
2)	137	326	2,495,894	2,523,626
2)	137	320	2,551,358	

E= 2,426,753 psi

16,736 MPa

Workability:

runny, nice, pretty self finishing

Batch # **20** DATE: N/A

D.R.U.W.	124.76	#/c.f.
Air Temp.	90.5	°F
Rel. Hum.	47	%
Conc. Temp.	86.5	°F
Slump	1.125	in.
Unit Wt.	143.95	#/c.f.
Air Content	6	%

M.C.

	CA	***IA***	***FA***
P	N/A	N/A	N/A
W+P	N/A	N/A	N/A
D+P	N/A	N/A	N/A
%	N/A	N/A	N/A
		(3/8 chip)	

Compression:

Days	avg. psi	avg. MPa.
0	0	0
1	2082	14
3	3616	25
28	4314	30
56	3910	27

Shrinkage:

Days	avg. % Microstrain
0	0
1	0
3	-98
7	-230
14	-263
21	-292
28	-305
56	-325

Modulus of Elasticity:

	psi
E=	3,443,396
	MPa
	23,748

Workability:

Batch # **21**

DATE: N/A

D.R.U.W.	128.76	#/c.f.
Air Temp.	89.5	°F
Rel. Hum.	46.5	%
Conc. Temp.	85	°F
Slump	0.75	in.
Unit Wt.	143.9	#/c.f.
Air Content	8	%

M.C.

	CA	*IA*	*FA*
P	N/A	N/A	N/A
W+P	N/A	N/A	N/A
D+P	N/A	N/A	N/A
%	N/A	N/A	N/A

(3/8 chip)

Compression:

Days	avg. psi	avg. MPa.
0	0	0
1	2011	14
4	3431	24
28	4006	28
56	3804	26

Shrinkage:

Days	avg. % Microstrain
0	0
1	0
4	-85
8	-223
14	-265
21	-308
28	-318
56	-347

Modulus of Elasticity:

E= psi 3,342,821

MPa 23,054

Workability:

Batch # **22** DATE: 7/25/2005

D.R.U.W.	123.2	#/c.f.	
Air Temp.	96	°F	
Rel. Hum.	41	%	
Conc. Temp.	89	°F	
Slump	0.5	in.	
Unit Wt.	150	#/c.f.	
Air Content	6	%	

M.C.

	CA	*IA*	*FA*
P	1.14	0.52	1.4
W+P	10.04	2.94	9.13
D+P	10.03	2.93	9.04
%	0.11	0.41	1.18
		(3/8 chip)	

Compression:

Days	psi	fracture style
1	3344	cone & shear
	3548	cone & shear
	3344	shear
4	4783	chip
	5007	chip
	4996	N/R
28	5469	chip
	5574	chip
	6250	shear
56	5734	columnar
	5631	columnar
	5844	N/R

Days	avg. psi	avg. MPa.
0	0	0
1	3412	24
4	4929	34
28	5764	40
56	5736	40

Shrinkage:

Days	a) +1800		b) +2000		c) +1800		avg. % Microstrain
0	0		0		0		0
1	24	0	8	0	92	0	0
4	10	-140	98	-100	77	-150	-130
8	1	-230	87	-210	68	-240	-227
14	92	-320	78	-300	60	-320	-313
21	89	-350	75	-330	57	-350	-343
28	89	-350	74	-340	56	-360	-350
56	85	-390	70	-380	54	-380	-383

Modulus of Elasticity:

$0.4 f'_c =$ 2305.7

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	261	629	3,531,491	3,543,292
1)	258	626	3,555,093	
2)	248	601	3,734,543	3,762,247
2)	244	594	3,789,951	

E= psi 3,652,769 MPa 25,192

Workability:
dry, rocky

Batch # **23**

DATE: 7/25/2005

D.R.U.W.	128.8	#/c.f.
Air Temp.	94	°F
Rel. Hum.	41	%
Conc. Temp.	89	°F
Slump	0.25	in.
Unit Wt.	148	#/c.f.
Air Content	5.4	%

M.C.

	CA	*IA*	*FA*
P	1.14	0.52	1.4
W+P	10.04	2.94	9.13
D+P	10.03	2.93	9.04
%	0.11	0.41	1.18
		(3/8 chip)	

Compression:

Days	psi	fracture style
1	2453	columnar
	1980	columnar
	2426	columnar
4	4652	columnar
	4331	chip
	4507	chip
28	5200	cone & split
	4880	chip
	5225	cone & split
56	5321	shear
	5236	columnar
	5163	shear

Days	avg. psi	avg. MPa.
0	0	0
1	2286	16
4	4497	31
28	5102	35
56	5240	36

Shrinkage:

Days	a) +1600		b) +1600		c) +1700		avg. % Microstrain
0	0		0		0		0
1	45	0	75	0	42	0	0
4	40	-50	73	-20	38	-40	-37
8	38	-70	63	-120	28	-140	-110
14	24	-210	56	-190	21	-210	-203
21	21	-240	54	-210	18	-240	-230
28	20	-250	53	-220	15	-270	-247
56	17	-280	49	-260	14	-280	-273

Modulus of Elasticity:

$0.4\ f'_c$= 2040.7

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	240	616	3,181,390	3,181,071
1)	234	618	3,180,751	
2)	221	587	3,388,579	3,395,847
2)	220	585	3,403,115	

E= 3,288,459 psi

22,679 MPa

Workability:

dry

Batch # **24** | DATE: 7/25/2005

D.R.U.W.	128.8	#/c.f.
Air Temp.	94	°F
Rel. Hum.	40	%
Conc. Temp.	87	°F
Slump	2.25	in.
Unit Wt.	151.1	#/c.f.
Air Content	3.3	%

M.C.

	CA	***IA***	***FA***
P	1.14	0.52	1.4
W+P	10.04	2.94	9.13
D+P	10.03	2.93	9.04
%	0.11	0.41	1.18
		(3/8 chip)	

Compression:

Days	**psi**	**fracture style**
1	2510	columnar
	2075	cone & shear
	2255	columnar
4	4888	chip
	4693	chip
	4894	chip
28	6212	chip
	6317	cone & split
	6500	columnar
56	6334	columnar
	6732	cone & split
	6008	shear

Days	**avg. psi**	**avg. MPa.**
0	0	0
1	2280	16
4	4825	33
28	6343	44
56	6358	44

Shrinkage:

Days	a) +400		b) +600		c) +1600		**avg. % Microstrain**
0	0		0		0		0
1	42	0	19	0	71	0	0
4	41	-10	17	-20	70	-10	-13
8	37	-50	11	-80	66	-50	-60
14	31	-110	5	-140	59	-120	-123
21	28	-140	2	-170	56	-150	-153
28	24	-180	99	-200	53	-180	-187
56	20	-220	95	-240	49	-220	-227

Modulus of Elasticity:

$0.4\ f'_c =$ 2537.2

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	352	514	4,709,483	4,638,144
1)	336	532	4,566,805	
2)	259	601	4,134,664	4,133,636
2)	256	602	4,132,609	

E= **psi** 4,385,890

MPa 30,248

Workability:
EXCELLENT, slushy

Batch #	**25**		DATE: 7/26/2005
D.R.U.W.	123.93	#/c.f.	
Air Temp.	79	°F	
Rel. Hum.	46	%	
Conc. Temp.	80	°F	
Slump	2	in.	
Unit Wt.	147.2	#/c.f.	
Air Content	5.3	%	

M.C.

	CA	*IA*	*FA*
P	0	0	0
W+P	0	0	0
D+P	0	0	0
%	0.00	0.00	0.00

(by sieve sizes)

Compression:

Days	psi	fracture style
1	2066	cone & shear
	2032	cone & shear
	1873	cone & shear
4	3648	chip
	3535	chip
	3726	shear
28	4084	cone
	4327	chip
	3912	chip
56	4063	chip
	4101	cone
	4047	chip

Days	avg. psi	avg. MPa.
0	0	0
1	1990	14
4	3636	25
28	4108	28
56	4070	28

Shrinkage:

Days	a) +600		b) +1300		c) +700		avg. % Microstrain
0	0		0		0		0
1	80	0	5	0	77	0	0
4	70	-100	95	-100	68	-90	-97
7	59	-210	82	-230	53	-240	-227
14	56	-240	81	-240	52	-250	-243
21	49	-310	77	-280	46	-310	-300
28	47	-330	76	-290	45	-320	-313
56	42	-380	70	-350	41	-360	-363

Modulus of Elasticity:

$0.4\,f'_c=$ 1643.1

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	205	461	3,498,946	3,486,963
1)	194	467	3,474,980	
2)	213	485	3,287,510	3,303,925
2)	212	481	3,320,340	

E= 3,395,444 psi

23,417 MPa

Workability:
sandy but nice

Batch #	26			DATE: 8/4/2005

D.R.U.W.	128.8	#/c.f.
Air Temp.	92	°F
Rel. Hum.	49	%
Conc. Temp.	86	°F
Slump	1.75	in.
Unit Wt.	141.5	#/c.f.
Air Content	5	%

M.C.

	CA	*IA*	*FA*
P	0.52	0.47	0.34
W+P	4.07	3.83	3.23
D+P	4.06	3.83	3.21
%	0.28	0.00	0.70
		(3/8 chip)	

Compression:

Days	psi	fracture style
1	1679	cone & shear
	1590	columnar
	1841	columnar
3	3086	cone & split
	3056	columnar
	3126	cone
28	3360	chip
	3116	shear
	3277	chip
56	3401	shear
	3637	chip
	3360	columnar

Days	avg. psi	avg. MPa.
0	0	0
1	1703	12
3	3089	21
28	3251	22
56	3466	24

Shrinkage:

Days	a) +1300		b) +1200		c) +1100		avg. % Microstrain
0	0		0		0		0
1	0	0	27	0	7	0	0
3	92	-80	18	-90	0	-70	-80
7	85	-150	9	-180	91	-160	-163
14	72	-280	6	-210	83	-240	-243
21	73	-270	1	-260	80	-270	-267
28	72	-280	98	-290	79	-280	-283
56	68	-320	94	-330	75	-320	-323

Modulus of Elasticity:

$0.4\ f'_c =$ 1300.4

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	185	429	2,943,008	2,959,945
1)	193	422	2,976,882	
2)	216	368	3,410,063	3,412,943
2)	221	366	3,415,823	

E= 3,186,444 psi

21,975 MPa

Workability:
descent, easy to consolidate

Batch #	27			DATE:	8/4/2005

D.R.U.W.	128.8	#/c.f.
Air Temp.	96	°F
Rel. Hum.	44	%
Conc. Temp.	78	°F
Slump	3.75	in.
Unit Wt.	134	#/c.f.
Air Content	11	%

M.C.

	CA	*IA*	*FA*
P	0.52	0.47	0.34
W+P	4.07	3.83	3.23
D+P	4.06	3.83	3.21
%	0.28	0.00	0.70
		(3/8 chip)	

Compression:

Days	psi	fracture style
1	1103	cone & split
	1114	cone & split
	1119	cone & shear
3	2031	shear
	1902	shear
	2012	shear
28	1771	chip
	1697	cone
	1927	chip
56	2029	chip
	2018	chip
	1945	N/R

Days	avg. psi	avg. MPa.
0	0	0
1	1112	8
3	1982	14
28	1798	12
56	1997	14

Shrinkage:

Days	a) +1500		b) +1600		c) +1400		avg. % Microstrain
0	0		0		0		0
1	5	0	0	0	2	0	0
3	93	-120	88	-120	89	-130	-123
7	83	-220	77	-230	80	-220	-223
14	71	-340	70	-300	72	-300	-313
21	74	-310	67	-330	70	-320	-320
28	72	-330	64	-360	70	-320	-337
56	69	-360	60	-400	64	-380	-380

Modulus of Elasticity:

$0.4\ f'_c=$ 719.3

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	271	231	2,476,980	2,508,331
1)	186	260	2,539,683	
2)	158	260	2,673,016	2,682,913
2)	170	254	2,692,810	

E=

psi
2,595,622
MPa
17,901

Workability:
N/R

Batch # **28**

DATE: 8/4/2005

D.R.U.W.	128.8	#/c.f.
Air Temp.	90	°F
Rel. Hum.	48	%
Conc. Temp.	80	°F
Slump	1.25	in.
Unit Wt.	145.4	#/c.f.
Air Content	5.1	%

M.C.

	CA	***IA***	***FA***
P	0.52	0.47	0.34
W+P	4.07	3.83	3.23
D+P	4.06	3.83	3.21
%	0.28	0.00	0.70
		(3/8 chip)	

Compression:

Days	psi	fracture style
1	1796	cone & split
	1803	cone & split
	1846	cone & split
3	3797	chip
	3530	shear
	3626	cone & split
28	3727	chip
	4105	shear
	3829	columnar
56	3785	cone
	3848	shear
	3759	chip

Days	avg. psi	avg. MPa.
0	0	0
1	1815	13
3	3651	25
28	3887	27
56	3797	26

Shrinkage:

Days	a) +1300		b) +1300		c) +1200		avg. % Microstrain
0	0		0		0		0
1	47	0	22	0	3	0	0
3	38	-90	12	-100	95	-80	-90
7	34	-130	5	-170	91	-120	-140
14	27	-200	99	-230	84	-190	-207
21	26	-210	99	-230	82	-210	-217
28	24	-230	96	-260	79	-240	-243
56	21	-260	29	-930	75	-280	-270

Modulus of Elasticity:

$0.4\ f'_c=$ 1554.8

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	272	413	3,533,884	3,597,220
1)	237	410	3,660,556	
2)	251	422	3,504,839	3,516,529
2)	267	415	3,528,219	

E= **psi** 3,556,874

MPa 24,530

Workability:

like #26, descent, easy to consolidate

Batch # **29** DATE: 8/8/2005

D.R.U.W.	128.8	#/c.f.
Air Temp.	N/R	°F
Rel. Hum.	N/R	%
Conc. Temp.	84	°F
Slump	1.75	in.
Unit Wt.	150.12	#/c.f.
Air Content	3.4	%

M.C.

	CA	*IA*	*FA*
P	0.47	0.34	0.52
W+P	4.69	2.9	3.21
D+P	4.69	2.9	3.15
%	0.00	0.00	2.28
		(3/8 chip)	

Compression:

Days	psi	fracture style
1	2287	crushed
	2188	columnar
	2231	cone & shear
3	4162	cone & shear
	4097	cone & shear
	4133	cone & shear
28	5913	cone & shear
	5816	chip
	6021	chip
56	6420	shear
	6228	chip
	6451	cone & split

Days	avg. psi	avg. MPa.
0	0	0
1	2235	15
3	4131	28
28	5917	41
56	6366	44

Shrinkage:

Days	a) +900		b) +1200		c) +900		avg. % Microstrain
0	0		0		0		0
1	92	0	22	0	30	0	0
3	91	-10	22	0	30	0	-3
7	86	-60	17	-50	23	-70	-60
14	78	-140	11	-110	15	-150	-133
21	76	-160	7	-150	12	-180	-163
28	71	-210	4	-180	8	-220	-203
56	65	-270	0	-220	4	-260	-250

Modulus of Elasticity:

0.4 f'_c= 2366.7

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	290	524	4,381,153	4,328,377
1)	293	535	4,275,601	
2)	285	560	4,081,699	4,057,450
2)	342	552	4,033,201	

E= **psi** 4,192,914 **MPa** 28,917

Workability:
N/R

Batch # **30**

DATE: 8/8/2005

D.R.U.W.	128.8	#/c.f.
Air Temp.	88	°F
Rel. Hum.	54	%
Conc. Temp.	79	°F
Slump	2.25	in.
Unit Wt.	149.44	#/c.f.
Air Content	3.8	%

M.C.

	CA	*IA*	*FA*
P	0.47	0.34	0.52
W+P	4.69	2.9	3.21
D+P	4.69	2.9	3.15
%	0.00	0.00	2.28
		(3/8 chip)	

Compression:

Days	psi	fracture style
1	1923	shear
	2045	shear
	2042	shear
3	4151	cone & shear
	4130	cone & shear
	4170	cone & shear
28	5607	chip
	5301	chip
	5656	chip
56	5949	cone
	6019	chip
	5908	chip

Days	avg. psi	avg. MPa.
0	0	0
1	2003	14
3	4150	29
28	5521	38
56	5959	41

Shrinkage:

Days	a) +1000		b) +1300		c) +900		avg. % Microstrain
0	0		0		0		0
1	73	0	21	0	27	0	0
3	73	0	20	-10	27	0	-3
7	70	-30	14	-70	22	-50	-50
14	61	-120	7	-140	15	-120	-127
21	57	-160	3	-180	11	-160	-167
28	54	-190	1	-200	8	-190	-193
56	50	-230	96	-250	4	-230	-237

Modulus of Elasticity:

$0.4\ f'_c=$ 2208.5

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	275	527	4,053,529	4,087,684
1)	296	514	4,121,839	
2)	301	479	4,446,465	4,478,455
2)	251	484	4,510,445	

E= **psi** 4,283,070

MPa 29,538

Workability:

N/R, but same as all SR mixes

Batch # **31**

DATE: 8/13/2005

D.R.U.W.	128.8	#/c.f.
Air Temp.	82	°F
Rel. Hum.	87	%
Conc. Temp.	80	°F
Slump	1.5	in.
Unit Wt.	150.88	#/c.f.
Air Content	3.4	%

M.C.

	CA	*IA*	*FA*
P	0.47	0.52	0.34
W+P	4.46	2.58	2.06
D+P	4.45	2.58	1.94
%	0.25	0.00	7.50
		(3/8 chip)	

Compression:

Days	psi	fracture style
1	2730	cone
	2787	columnar
	2812	cone & split
3	5010	columnar
	5416	columnar
	4883	columnar
28	6482	chip
	6888	chip
	6670	chip
56	6899	cone & split
	6923	chip
	7071	chip

Days	avg. psi	avg. MPa.
0	0	0
1	2776	19
3	5103	35
28	6680	46
56	6964	48

Shrinkage:

Days	a) +1100		b) +1000		c) +1300		avg. % Microstrain
0	0		0		0		0
1	70	0	19	0	90	0	0
3	65	-50	14	-50	87	-30	-43
7	52	-180	10	-90	84	-60	-110
14	54	-160	3	-160	78	-120	-147
21	51	-190	0	-190	75	-150	-177
28	49	-210	99	-200	74	-160	-190
56	44	-260	92	-270	68	-220	-250

Modulus of Elasticity:

$0.4\ f'_c=$ 2672

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	256	594	4,441,176	4,467,779
1)	272	584	4,494,382	
2)	304	550	4,736,000	4,766,374
2)	312	542	4,796,748	

E= psi 4,617,077

MPa 31,842

Workability:

little drier than before, still pretty good, easy finish

Batch #	32			DATE:	8/13/2005

D.R.U.W.	128.8	#/c.f.
Air Temp.	72	°F
Rel. Hum.	88	%
Conc. Temp.	76	°F
Slump	1	in.
Unit Wt.	151.24	#/c.f.
Air Content	3.3	%

M.C.

	CA	*IA*	*FA*
P	0.47	0.52	0.34
W+P	4.46	2.58	2.06
D+P	4.45	2.58	1.94
%	0.25	0.00	7.50
		(3/8 chip)	

Compression:

Days	psi	fracture style
1	2550	split & cone
	2739	chip
	2443	chip
3	4773	shear
	5082	cone & shear
	4700	shear
28	6772	shear
	6619	columnar
	6899	cone & split
56	7125	chip
	7036	chip
	7434	chip

Days	avg. psi	avg. MPa.
0	0	0
1	2577	18
3	4852	33
28	6763	47
56	7198	50

Shrinkage:

Days	a) +600		b) +1200		c) +1200		avg. % Microstrain
0	0		0		0		0
1	54	0	36	0	89	0	0
3	49	-50	32	-40	86	-30	-40
7	44	-100	27	-90	83	-60	-83
14	35	-190	22	-140	77	-120	-150
21	32	-220	19	-170	73	-160	-183
28	29	-250	16	-200	70	-190	-213
56	23	-310	11	-250	65	-240	-267

Modulus of Elasticity:

$0.4\ f'_c =$ 2705.3

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	307	554	4,758,598	4,762,865
1)	317	551	4,767,132	
2)	266	579	4,611,216	4,621,164
2)	274	575	4,631,111	

E= 4,692,014 psi

32,359 MPa

Workability:

N/R

Batch #	34			DATE:	8/15/2005

D.R.U.W.	128.8	#/c.f.
Air Temp.	N/R	°F
Rel. Hum.	N/R	%
Conc. Temp.	N/R	°F
Slump	3.25	in.
Unit Wt.	142.4	#/c.f.
Air Content	3.3	%

M.C.

	CA	*IA*	*FA*
P	N/A	N/A	N/A
W+P	N/A	N/A	N/A
D+P	N/A	N/A	N/A
%	N/A	N/A	N/A
		(3/8 chip)	

Compression:

Days	psi	fracture style
1	1547	cone & shear
	1493	cone & shear
	1520	columnar
3	2849	cone & shear
	2905	cone & shear
	2854	cone & shear
28	3817	chip
	3789	chip
	3683	chip
56	3715	cone
	3839	chip
	3898	cone

Days	avg. psi	avg. MPa.
0	0	0
1	1520	10
3	2869	20
28	3763	26
56	3817	26

Shrinkage:

Days	a) +900		b) +1400		c) +1400		avg. % Microstrain
0	0		0		0		0
1	30	0	72	0	50	0	0
3	23	-70	65	-70	36	-140	-93
7	14	-160	57	-150	27	-230	-180
14	8	-220	50	-220	19	-310	-250
21	5	-250	47	-250	12	-380	-293
28	4	-260	46	-260	15	-350	-290
56	0	-300	42	-300	10	-400	-333

Modulus of Elasticity:

$0.4\ f'_c =$ 1505.2

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	94	627	2,445,754	2,688,351
1)	113	525	2,930,947	
2)	25	712	2,235,952	2,558,485
2)	33	561	2,881,018	

E=	psi: 2,623,418
	MPa: 18,093

Workability:

N/R

Batch # **35** DATE: 8/15/2005

D.R.U.W.	128.8	#/c.f.
Air Temp.	78	°F
Rel. Hum.	76	%
Conc. Temp.	80	°F
Slump	1.25	in.
Unit Wt.	150.8	#/c.f.
Air Content	3.5	%

M.C.

	CA	***IA***	***FA***
P	N/A	N/A	N/A
W+P	N/A	N/A	N/A
D+P	N/A	N/A	N/A
%	N/A	N/A	N/A
		(3/8 chip)	

Compression:

Days	psi	fracture style
1	1816	cone & shear
	1856	columnar
	1749	cone & shear
3	4041	columnar
	4020	columnar
	3882	shear
28	4701	chip
	5894	chip
	5419	chip
56	5822	shear
	6037	chip
	5753	chip

Days	avg. psi	avg. MPa.
0	0	0
1	1807	12
3	3981	27
28	5338	37
56	5871	40

Shrinkage:

Days	a) +900		b) +1300		c) +1300		avg. % Microstrain
0	0		0		0		0
1	44	0	15	0	45	0	0
3	41	-30	11	-40	40	-50	-40
7	35	-90	7	-80	36	-90	-87
14	29	-150	1	-140	29	-160	-150
21	26	-180	98	-170	26	-190	-180
28	24	-200	96	-190	23	-220	-203
56	18	-260	92	-230	18	-270	-253

Modulus of Elasticity:

0.4 f'_c= 2135.2

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	259	492	4,244,796	4,232,984
1)	261	494	4,221,171	
2)	245	483	4,365,358	4,359,514
2)	237	486	4,353,670	

E= 4,296,249 psi

29,629 MPa

Workability:

N/R

Batch # **36** DATE: 8/16/2005

D.R.U.W.	128.8	#/c.f.	M.C.				
Air Temp.	78	°F		CA	IA	FA	
Rel. Hum.	76	%	P	1.13	0.47	1.4	
Conc. Temp.	80	°F	W+P	11.4	2.73	8.45	
Slump	5	in.	D+P	11.38	2.73	8.26	
Unit Wt.	149.48	#/c.f.	%	0.20	0.00	2.77	
Air Content	3.3	%			(3/8 chip)		

Compression:

Days	psi	fracture style
1	2005	cone & shear
	1937	columnar
	1962	columnar
3	4251	cone & shear
	4113	cone & shear
	4276	shear
28	6707	chip
	5983	columnar
	6018	shear
56	6217	chip
	5965	split & cone
	6107	columnar

Days	avg. psi	avg. MPa.
0	0	0
1	1968	14
3	4213	29
28	6236	43
56	6096	42

Shrinkage:

Days	a) +1300		b) +1200		c) +1000		avg. % Microstrain
0	0		0		0		0
1	11	0	72	0	29	0	0
3	8	-30	71	-10	29	0	-13
10	1	-100	64	-80	22	-70	-83
14	97	-140	60	-120	18	-110	-123
25	92	-190	56	-160	13	-160	-170
28	91	-200	56	-160	12	-170	-177
56	84	-270	57	-150	7	-220	-213

Modulus of Elasticity:

0.4 f'_c= 2494.4

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	237	566	4,374,806	4,396,458
1)	250	558	4,418,110	
2)	237	594	4,149,632	4,169,983
2)	240	588	4,190,335	

E= 4,283,221 psi

29,539 MPa

Workability:

N/R

Batch #	37			DATE:	8/17/2005

D.R.U.W.	128.8	#/c.f.
Air Temp.	N/R	°F
Rel. Hum.	N/R	%
Conc. Temp.	80	°F
Slump	2.25	in.
Unit Wt.	141.88	#/c.f.
Air Content	8.5	%

M.C.

	CA	***IA***	***FA***
P	0.52	0.47	0.57
W+P	6.01	2.75	2.8
D+P	5.98	2.75	2.74
%	0.55	0.00	2.76
		(3/8 chip)	

Compression:

Days	psi	fracture style
1	1574	columnar
	1646	columnar
	1420	cone & shear
3	2539	shear
	2679	shear
	3110	shear
28	3501	shear
	3239	chip
	3478	shear
56	3376	columnar
	3357	split & cone
	3339	columnar

Days	avg. psi	avg. MPa.
0	0	0
1	1547	11
3	2776	19
28	3406	23
56	3357	23

Shrinkage:

Days	a) +1200		b) +1000		c) +1000		avg. % Microstrain
0	0		0		0		0
1	36	0	81	0	5	0	0
3	28	-80	71	-100	95	-100	-93
10	8	-280	53	-280	75	-300	-287
14	15	-210	49	-320	71	-340	-330
21	1	-350	44	-370	66	-390	-370
28	97	-390	42	-390	64	-410	-397
56	91	-450	36	-450	58	-470	-457

Modulus of Elasticity:

$0.4\ f'_c=$ 1362.4

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	216	417	3,123,706	3,116,447
1)	212	420	3,109,189	
2)	151	481	2,810,673	2,828,796
2)	161	472	2,846,919	

E= 2,972,622 psi

20,501 MPa

Workability:

very good, rocky but easy

Batch # **38** DATE: 8/18/2005

D.R.U.W.	128.8	#/c.f.
Air Temp.	92	°F
Rel. Hum.	47	%
Conc. Temp.	80	°F
Slump	0	in.
Unit Wt.	149.2	#/c.f.
Air Content	5	%

M.C.

	CA	*IA*	*FA*
P	0.57	0.52	0.47
W+P	6.21	4.22	3.32
D+P	6.19	4.22	3.2
%	0.36	0.00	4.40
		(3/8 chip)	

Compression:

Days	psi	fracture style
1	2757	shear
	2838	shear
	3033	columnar
3	4940	chip
	4522	cone & split
	4990	shear
28	6503	chip
	6314	chip
	6355	shear
56	5871	columnar
	5827	chip
	6318	chip

Days	avg. psi	avg. MPa.
0	0	0
1	2876	20
3	4817	33
28	6391	44
56	6005	41

Shrinkage:

Days	a) +1200		b) +1000		c) +1200		avg. % Microstrain
0	0		0		0		0
1	66	0	22	0	0	0	0
3	60	-60	15	-70	93	-70	-67
7	49	-170	7	-150	87	-130	-150
14	44	-220	2	-200	83	-170	-197
25	41	-250	98	-240	79	-210	-233
28	39	-270	98	-240	79	-210	-240
56	35	-310	94	-280	75	-250	-280

Modulus of Elasticity:

$0.4\ f'_c=$ 2556.3

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	337	588	4,125,031	4,161,093
1)	294	589	4,197,155	
2)	264	620	4,021,520	4,061,451
2)	280	605	4,101,381	

E= 4,111,272 psi

28,354 MPa

Workability:

very dry, hard to finish

Batch #	39			DATE:	8/18/2005

D.R.U.W.	128.8	#/c.f.
Air Temp.	92	°F
Rel. Hum.	47	%
Conc. Temp.	80	°F
Slump	0	in.
Unit Wt.	N/R	#/c.f.
Air Content	4.6	%

M.C.

	CA	*IA*	*FA*
P	0.57	0.52	0.47
W+P	6.21	4.22	3.32
D+P	6.19	4.22	3.2
%	0.36	0.00	4.40
		(3/8 chip)	

Compression:

Days	psi	fracture style
1	2480	shear
	2583	shear
	2639	columnar
3	4517	shear
	4891	cone & split
	4638	N/R
28	5944	columnar
	5820	shear
	5994	columnar
56	5874	chip
	5715	chip
	5077	chip

Days	avg. psi	avg. MPa.
0	0	0
1	2567	18
3	4682	32
28	5919	41
56	5555	38

Shrinkage:

Days	a) +1100		b) +900		c) +1100		avg. % Microstrain
0	0		0		0		0
1	25	0	35	0	38	0	0
3	15	-100	27	-80	31	-70	-83
7	6	-190	18	-170	24	-140	-167
14	0	-250	13	-220	19	-190	-220
25	97	-280	9	-260	15	-230	-257
28	96	-290	9	-260	15	-230	-260
56	92	-330	5	-300	10	-280	-303

Modulus of Elasticity:

$0.4 f'_c=$ 2367.7

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	53	660	3,794,645	3,684,946
1)	76	691	3,575,247	
2)	226	562	4,183,073	4,208,504
2)	255	549	4,233,935	

E= 3,946,725 psi

27,219 MPa

Workability:

N/R

Batch # **40** DATE: 8/24/2005

D.R.U.W.	128.8	#/c.f.	M.C.				
					CA	IA	FA
Air Temp.	93	°F		P	0.34	0.52	0.47
Rel. Hum.	50	%		W+P	3.74	2.86	2.75
Conc. Temp.	80	°F		D+P	3.74	2.86	2.71
Slump	1.5	in.		%	0.00	0.00	1.79
Unit Wt.	147.82	#/c.f.				(3/8 chip)	
Air Content	6.7	%					

Compression:

Days	psi	fracture style
1	4015	columnar
	3874	shear
	3748	cone
3	4681	cone & split
	4450	cone & split
	4525	shear
28	5800	shear
	5515	chip
	5535	cone & split
56	5166	chip
	5745	columnar
	5905	crushed

Days	avg. psi	avg. MPa.
0	0	0
1	3879	27
3	4552	31
28	5617	39
56	5605	39

Shrinkage:

Days	a) +1200		b) +1200		c) +1300		avg. % Microstrain
0	0		0		0		0
1	22	0	28	0	71	0	0
3	14	-80	19	-90	64	-70	-80
8	6	-160	10	-180	55	-160	-167
14	99	-230	4	-240	48	-230	-233
21	96	-260	1	-270	45	-260	-263
28	95	-270	99	-290	43	-280	-280
56	90	-320	95	-330	39	-320	-323

Modulus of Elasticity:

$0.4\,f'_c=$ 2246.7

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{\text{each test}}$	$E_{\text{each spec.}}$
1)	24	641	3,760,857	3,894,645
1)	27	601	4,028,433	
2)	38	1086	2,131,918	2,238,305
2)	45	989	2,344,693	

E= 3,066,475 psi

21,148 MPa

Workability:

like all tetraguard mixes, good

Batch # **41** DATE: 8/24/2005

D.R.U.W.	128.8	#/c.f.
Air Temp.	94	°F
Rel. Hum.	49	%
Conc. Temp.	81	°F
Slump	1	in.
Unit Wt.	149.2	#/c.f.
Air Content	5.8	%

M.C.

	CA	*IA*	*FA*
P	0.34	0.52	0.47
W+P	3.74	2.86	2.75
D+P	3.74	2.86	2.71
%	0.00	0.00	1.79
		(3/8 chip)	

Compression:

Days	psi	fracture style
1	4165	chip
	4138	columnar
	4036	shear
3	5099	helical
	5357	crumbled
	5344	split & shear
28	6579	columnar
	6422	chip
	6516	cone & split
56	6871	shear
	6298	shear
	7079	chip

Days	avg. psi	avg. MPa.
0	0	0
1	4113	28
3	5267	36
28	6506	45
56	6749	47

Shrinkage:

Days	a) +1400		b) +1400		c) +1400		avg. % Microstrain
0	0		0		0		0
1	58	0	28	0	57	0	0
3	50	-80	20	-80	49	-80	-80
7	42	-160	11	-170	41	-160	-163
14	35	-230	4	-240	34	-230	-233
21	31	-270	0	-280	30	-270	-273
28	29	-290	98	-300	27	-300	-297
56	22	-360	92	-360	21	-360	-360

Modulus of Elasticity:

$0.4\, f'_c$= 2602.3

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	250	586	4,388,557	4,420,945
1)	242	580	4,453,333	
2)	240	604	4,264,019	4,279,420
2)	253	597	4,294,820	

E= 4,350,183 psi

30,001 MPa

Workability:

not as nice w/ f.a. but very nice

Batch # **42**

DATE: 8/24/2005

D.R.U.W.	128.8	#/c.f.
Air Temp.	94	°F
Rel. Hum.	47	%
Conc. Temp.	84	°F
Slump	1	in.
Unit Wt.	150.06	#/c.f.
Air Content	5	%

M.C.

	CA	*IA*	*FA*
P	0.34	0.52	0.47
W+P	3.74	2.86	2.75
D+P	3.74	2.86	2.71
%	0.00	0.00	1.79
		(3/8 chip)	

Compression:

Days	psi	fracture style
1	861	shear
	821	crumbly/duct.
2	3097	chip/ductile
3	4611	chip/ductile
	4138	N/R
	4218	columnar
28	4870	cone
	5311	columnar
	5728	chip
56	5672	shear (helical)
	5879	chip
	5216	columnar

Days	avg. psi	avg. MPa.
0	0	0
1	841	6
2	3097	21
3	4322	30
28	5303	37
56	5589	39

Shrinkage:

Days	a) +1600		b) +2400		c) +1400		avg. % Microstrain
0	0		0		0		0
1	74	0	81	0	1	0	0
3	66	-80	73	-80	94	-70	-77
7	53	-210	65	-160	86	-150	-173
14	43	-310	58	-230	81	-200	-247
21	38	-360	56	-250	78	-230	-280
28	35	-390	55	-260	75	-260	-303
56	30	-440	50	-310	72	-290	-347

Modulus of Elasticity:

$0.4\ f'_c$= 2121.2

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	231	531	3,929,730	3,961,905
1)	232	523	3,994,080	
2)	245	539	3,836,810	3,868,923
2)	237	533	3,901,035	

E= 3,915,414 psi

27,003 MPa

Workability:

looks like a wet mouse, pretty easy finish

Batch #	43			DATE:	8/24/2005

D.R.U.W.	128.8	#/c.f.
Air Temp.	87	°F
Rel. Hum.	58	%
Conc. Temp.	84	°F
Slump	1	in.
Unit Wt.	148.85	#/c.f.
Air Content	5.5	%

M.C.

	CA	***IA***	***FA***
P	0.52	0.34	0.47
W+P	2.87	1.62	2.88
D+P	2.85	1.62	2.83
%	0.86	0.00	2.12
		(3/8 chip)	

Compression:

Days	psi	fracture style
1	2814	chip
	2836	chip
	2884	cracks
3	5336	shear
	5231	chip
	5454	split & shear
28	6896	chip
	6785	chip
	7138	split & cone
56	6761	cone & split
	6969	cone
	6691	chip

Days	avg. psi	avg. MPa.
0	0	0
1	2845	20
3	5340	37
28	6940	48
56	6807	47

Shrinkage:

Days	a) +1600		b) +1200		c) +800		avg. % Microstrain
0	0		0		0		0
1	50	0	68	0	67	0	0
3	46	-40	61	-70	62	-50	-53
7	35	-150	52	-160	53	-140	-150
14	28	-220	45	-230	46	-210	-220
21	25	-250	41	-270	42	-250	-257
28	23	-270	39	-290	40	-270	-277
56	18	-320	35	-330	36	-310	-320

Modulus of Elasticity:

0.4 f'_c= 2775.9

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	215	704	3,915,698	3,951,495
1)	224	690	3,987,292	
2)	360	709	3,665,959	3,704,958
2)	215	734	3,743,957	

E= 3,828,226 psi

26,402 MPa

Workability:

better than fibers w/out f.a., not too bad

Batch # **44** DATE: 9/5/2005

D.R.U.W.	128.8	#/c.f.
Air Temp.	88	°F
Rel. Hum.	39	%
Conc. Temp.	83	°F
Slump	0.5	in.
Unit Wt.	145.8	#/c.f.
Air Content	5.5	%

M.C.

	CA	*IA*	*FA*
P	0.52	0.34	0.47
W+P	2.94	2.49	2.27
D+P	2.94	2.48	2.23
%	0.00	0.47	2.27
		(3/8 chip)	

Compression:

Days	psi	fracture style
1	3980	columnar
	3973	shear
	3945	columnar
3	5537	columnar
	5206	shear
	5489	shear
28	6470	cone
	6977	columnar
	6790	cone
56	6850	split & cone
	6840	columnar
	6492	columnar

Days	avg. psi	avg. MPa.
0	0	0
1	3966	27
3	5411	37
28	6746	47
56	6872	47

Shrinkage:

Days	a) +1300		b) +1000		c) +700		avg. % Microstrain
0	0		0		0		0
1	22	0	46	0	66	0	0
3	17	-50	40	-60	62	-40	-50
7	4	-180	26	-200	48	-180	-187
14	98	-240	19	-270	39	-270	-260
21	95	-270	17	-290	36	-300	-287
28	93	-290	14	-320	34	-320	-310
56	91	-310	12	-340	31	-350	-333

Modulus of Elasticity:

$0.4\ f'_c=$ 2698.3

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	19	1268	2,199,726	2,341,174
1)	22	1128	2,482,622	
2)	263	631	4,191,509	4,206,329
2)	250	630	4,221,149	

E= 3,273,752 psi

22,578 MPa

Workability:
drier

Batch # **slab 1** DATE: 10/26/2005

D.R.U.W.	unknown	#/c.f.
Air Temp.	78	°F
Rel. Hum.	37	%
Conc. Temp.	80	°F
Slump	3.5	in.
Unit Wt.	135.7	#/c.f.
Air Content	11.5	%

M.C.

	CA	***IA***	***FA***
P	N/A	N/A	N/A
W+P	N/A	N/A	N/A
D+P	N/A	N/A	N/A
%	N/A	N/A	N/A
		(3/8 chip)	

Compression:

Days	**psi**	**fracture style**
1	1600	shear (brittle)
	1592	chip
	1542	shear
3	3054	shear
	3428	columnar
	3150	chip
7	4404	cone & split
	4609	shattered
	4121	columnar
28	4665	shear
	4580	chip
	4030	chip
56	4862	columnar
	4849	chip
	4709	columnar

Days	**avg. psi**	**avg. MPa.**
0	0	0
1	1578	11
3	3211	22
7	4378	30
28	4425	31
56	4807	33

Shrinkage:

Days	a) +1000		b) +800		c) +1300		**avg. % Microstrain**
0	0		0		0		0
1	25	0	97	0	62	0	0
3	18	-70	90	-70	55	-70	-70
7	7	-180	77	-200	46	-160	-180
14	N/A	N/A	N/A	N/A	N/A	N/A	N/A
21	N/A	N/A	N/A	N/A	N/A	N/A	N/A
28	92	-330	63	-340	35	-270	-313
56	90	-350	60	-370	32	-300	-340

Modulus of Elasticity:

$0.4\ f'_c =$ 1770.0

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	216	477	3,639,344	3,629,531
1)	228	476	3,619,718	
2)	220	524	3,270,042	3,273,386
2)	207	527	3,276,730	

E= **psi** 3,451,459 **MPa** 23,803

Workability:
nice, flowy, slushy

Batch # **slab 2** DATE: 10/26/2005

D.R.U.W.	unkown	#/c.f.
Air Temp.	78	°F
Rel. Hum.	38	%
Conc. Temp.	78	°F
Slump	5	in.
Unit Wt.	129.7	#/c.f.
Air Content	13.5	%

M.C.

	CA	*IA*	*FA*
P	N/A	N/A	N/A
W+P	N/A	N/A	N/A
D+P	N/A	N/A	N/A
%	N/A	N/A	N/A
		(3/8 chip)	

Compression:

Days	psi	fracture style
1	886	cone (crumbly)
	837	shear
	842	chip
3	2211	chip
	2278	shear
	2352	ductile
7	3027	shear
	2997	columnar
	3067	shear
28	3129	shear
	2989	shear
	3129	shear
56	2919	shear
	2965	shear
	2941	chip

Days	avg. psi	avg. MPa.
0	0	0
1	855	6
3	2280	16
7	3030	21
28	3082	21
56	2942	20

Shrinkage:

Days	a) +1200		b) +1300		c) +1000		avg. % Microstrain
0	0		0		0		0
1	30	0	33	0	24	0	0
3	71	410	22	-110	13	-110	-110
7	50	200	5	-280	95	-290	-285
14	N/A	N/A	N/A	N/A	N/A	N/A	N/A
21	N/A	N/A	N/A	N/A	N/A	N/A	N/A
28	30	-1000	90	-430	80	-440	-435
56	26	-1040	88	-450	77	-470	-460

Modulus of Elasticity:

0.4 f'_c= 1232.9

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	175	472	2,506,951	2,517,818
1)	181	466	2,528,686	
2)	164	477	2,503,357	2,534,474
2)	199	453	2,565,591	

E= psi 2,526,146

MPa 17,422

Workability:

added 25 gals of water, then nice, was thick and stuck in truck

Batch # **slab 3**

DATE: 10/26/2005

D.R.U.W.	unknown	#/c.f.
Air Temp.	78	°F
Rel. Hum.	38	%
Conc. Temp.	76	°F
Slump	3.5	in.
Unit Wt.	137.7	#/c.f.
Air Content	9.5	%

M.C.

	CA	*IA*	*FA*
P	N/A	N/A	N/A
W+P	N/A	N/A	N/A
D+P	N/A	N/A	N/A
%	N/A	N/A	N/A

(3/8 chip)

Compression:

Days	psi	fracture style
1	1926	cone (crumbly)
	1908	shear
	2015	chip
3	4382	columnar
	4335	split & cone
	4339	split & cone
7	5357	split & cone
	5171	shear
	5486	chip
28	5707	columnar
	5725	chip
	6474	columnar
56	5430	chip
	5580	shear
	5322	shear

Days	avg. psi	avg. MPa.
0	0	0
1	1950	13
3	4352	30
7	5338	37
28	5969	41
56	5444	38

Shrinkage:

Days	a) +1100		b) +1100		c) +1200		avg. % Microstrain
0	0		0		0		0
1	80	0	70	0	53	0	0
3	71	-90	62	-80	45	-80	-80
7	55	-250	48	-220	31	-220	-220
14	N/A	N/A	N/A	N/A	N/A	N/A	N/A
21	N/A	N/A	N/A	N/A	N/A	N/A	N/A
28	35	-1450	28	-420	15	-380	-400
56	31	-1490	25	-450	12	-410	-430

Modulus of Elasticity:

$0.4 f'_c =$ 2387.5

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	183	703	3,375,906	3,377,912
1)	177	704	3,379,918	
2)	173	698	3,417,387	3,382,300
2)	185	708	3,347,214	

E= 3,380,106 psi

23,311 MPa

Workability:

added 25 gals of water, then nice runny and dries fast, was thick and stuck in truck

Batch # **Span 1** DATE: 4/26/2006

D.R.U.W.	N/A	#/c.f.
Air Temp.	61	°F
Rel. Hum.	48	%
Conc. Temp.	65	°F
Slump	3.0 - 5.0	in.
Unit Wt.	N/A	#/c.f.
Air Content	7.2 - 9.0	%

M.C.

	CA	*IA*	*FA*
P	N/A	N/A	N/A
W+P	N/A	N/A	N/A
D+P	N/A	N/A	N/A
%	N/A	N/A	N/A
		(3/8 chip)	

Compression:

Days	psi	fracture style
1	2481	chip
	2500	chip
	2346	shear
3	3521	chip
	3368	shear
	3684	cone
28	4985	shear
	5317	columnar
	4942	chip
56	N/A	N/A
	N/A	N/A
	N/A	N/A

Days	avg. psi	avg. MPa.
0	0	0
1	2442	17
3	3524	24
28	5081	35
56	N/A	N/A

Shrinkage:

Days	a) +1500		b) +1400		c) +700		avg. % Microstrain
0	0		0		0		0
1	94	0	0	0	74	0	0
3	88	-60	93	-70	65	-90	-73
7	80	-140	85	-150	58	-160	-150
14	75	-190	78	-220	53	-210	-207
21	67	-270	73	-270	46	-280	-273
28	68	-260	71	-290	47	-270	-273
56	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Modulus of Elasticity:

$0.4\ f'_c =$ 2032.5

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{each\ test}$	$E_{each\ spec.}$
1)	342	471	4,015,519	4,100,462
1)	350	452	4,185,406	
2)	213	497	4,070,544	4,043,587
2)	213	503	4,016,630	

E= psi 4,072,025

MPa 28,083

Splitting Tensile

Days	psi	average psi	average Mpa
28	1646	1679	12
	1590		
	1800		

Workability:

Batch #	**Span 2**			DATE:	4/26/2006

				M.C.		
D.R.U.W.	N/A	#/c.f.		***CA***	***IA***	***FA***
Air Temp.	62	°F	P	N/A	N/A	N/A
Rel. Hum.	48	%	W+P	N/A	N/A	N/A
Conc. Temp.	N/R	°F	D+P	N/A	N/A	N/A
Slump	4.0 - 7.5	in.	%	N/A	N/A	N/A
Unit Wt.	N/A	#/c.f.			(3/8 chip)	
Air Content	6.4 - 7.2	%				

Compression:

Days	psi	fracture style
1	3681	cone
	3863	cone
	3591	cone & split
3	5039	cone & split
	5255	helical
	5131	cone & split
28	6758	columnar
	7132	cone & split
	7038	shear
56	N/A	N/A
	N/A	N/A
	N/A	N/A

Days	avg. psi	avg. MPa.
0	0	0
1	3712	26
3	5142	35
28	6976	48
56	N/A	N/A

Shrinkage:

Days	a) +1600		b) +1600		c) +1600		avg. % Microstrain
0	0		0		0		0
1	82	0	52	0	26	0	0
3	74	-80	44	-80	18	-80	-80
7	68	-140	37	-150	11	-150	-147
14	62	-200	32	-200	6	-200	-200
21	56	-260	25	-270	99	-270	-267
28	57	-250	25	-270	0	-260	-260
56	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Modulus of Elasticity:

$0.4\ f'_c=$ 2790.4

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{\text{each test}}$	$E_{\text{each spec.}}$
1)	220	659	4,220,690	4,231,337
1)	224	655	4,241,983	
2)	232	638	4,351,020	4,357,903
2)	237	635	4,364,786	

	psi	MPa
E=	4,294,620	29,618

Splitting Tensile

Days	psi	average psi	average Mpa
28	2099	2131	15
	2177		
	2117		

Workability:

Batch #	Span 3			DATE:	5/2/2006

D.R.U.W.	N/A	#/c.f.
Air Temp.	71	°F
Rel. Hum.	89	%
Conc. Temp.	75	°F
Slump	5	in.
Unit Wt.	N/A	#/c.f.
Air Content	7.6 - 8.0	%

M.C.

	CA	***IA***	***FA***
P	N/A	N/A	N/A
W+P	N/A	N/A	N/A
D+P	N/A	N/A	N/A
%	N/A	N/A	N/A
		(3/8 chip)	

Compression:

Days	**psi**	**fracture style**
1	N/A	N/A
	N/A	N/A
	N/A	N/A
3	4248	columnar
	4754	ductile
	4577	columnar
28	6813	(brittle)columnar
	7138	columnar
	7060	chip
56	N/A	N/A
	N/A	N/A
	N/A	N/A

Days	**avg. psi**	**avg. MPa.**
0	0	0
1	N/A	N/A
3	4526	31
28	7004	48
56	N/A	N/A

Shrinkage:

Days	a) +1800		b) +1600		c) +1300		**avg. % Microstrain**
0	0		0		0		0
1	8	0	19	0	32	0	0
3	1	-70	12	-70	25	-70	-70
7	90	-180	0	-190	14	-180	-183
14	79	-290	88	-310	4	-280	-293
21	79	-290	88	-310	3	-290	-297
28	77	-310	85	-340	1	-310	-320
56	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Modulus of Elasticity:

$0.4\ f'_c =$ 2801.5

	$\sigma_{\epsilon 50}$	$\epsilon_{0.4\sigma}$	$E_{\text{each test}}$	$E_{\text{each spec.}}$
1)	266	637	4,319,364	4,329,327
1)	276	632	4,339,290	
2)	264	593	4,673,051	4,683,180
2)	253	593	4,693,309	

E= **psi** 4,506,253

MPa 31,078

Splitting Tensile

Days	**psi**	**average psi**	**average Mpa**
28	1954	1788	12
	1838		
	1571		

Workability:

Appendix D – Field Investigation Mix Design

- Actual Mix Design Used at the Batch Plant for the Test Slabs and Bridge Construction

MIXES FOR BECKHAM COUNTY
ODOT PROJECT IBR-105N(108), JP 2.296(06)

(Phase I – West Bound I-40)

	Mix Code 8965 P.C. Only Span 2	Mix Code 8994 P.C. + Fibers Span 3
Cement	574 lb	574 lb
Fly Ash	0 lb	0 lb
#57 Aggregate	1285 lb	1279 lb
3/8" Chip Aggregate	345 lb	343 lb
Sand	1505 lb	1498 lb
Water	214 lb	214 lb
Tetraguard® AS20	13.2 oz	13.2 oz
MB AE™ 90	42.3 oz	36.5 oz
Polyheed® 1020	79.5 oz	151.5 oz
Fibers	0 lb	5 lb

Appendix E – AVA Test Data

- Available Data from Test Slab AVA Tests

IBRC AVA TEST DATA

Batched 10/26/2005

TEST ORDER	SERIES ORDER	TEST DATE	Run ID	Mix ID	Location	Air in Concrete	Air in Paste	Air in Putty	Air Smaller than 300 um	% of Air less than 300 um	Specific Surface	Spacing Factor	Specimen Weight (lbs.)	Specimen After Test (lbs.)	Specimen Delta (lbs.)	Specimen % Remaining
2	R1-002	10/27/2005	1	Truck 1 Cement + Fly Ash	TRUCK	7.8%	32.9%	24.8%	3.4%	44%	688	0.0045	0.0905			
3	R2-002	10/28/2005	2			Specimen Damaged -- Invalid Test										
5	R3-002	10/30/2005	3			7.2%	30.3%	23.3%	2.6%	36%	617	0.0054	0.0861	0.0363	0.0498	42%
1	R1-001	10/27/2005	1		EOB	7.6%	32.2%	24.4%	2.6%	34%	522	0.0061	0.0836			
2	R2-001	10/28/2005	2			6.9%	28.7%	22.3%	2.2%	32%	510	0.0069	0.0880	0.0458	0.0422	52%
8	R3-001	10/30/2005	3			7.6%	31.9%	24.2%	2.0%	26%	428	0.0075	0.0852	0.0309	0.0544	36%
9	R1-009	10/28/2005	1		SLAB	5.5%	22.4%	18.3%	2.0%	36%	537	0.0082	0.0806			
5	R2-009	10/28/2005	2			6.0%	24.7%	19.8%	2.0%	33%	507	0.008	0.0861	0.0436	0.0425	51%
7	R3-009	10/30/2005	3			4.9%	19.9%	16.6%	1.6%	33%	479	0.0096	0.0790	0.0427	0.0363	54%
4	R1-004	10/27/2005	1	Truck #2 Cement + Fly Ash + Fibers	TRUCK	4.6%	19.0%	15.9%	1.8%	39%	566	0.0083				
4	R2-004	10/28/2005	2			5.1%	20.7%	17.1%	2.0%	39%	596	0.0076	0.0901			
3	R3-004	10/28/2005	3			4.6%	18.7%	15.8%	1.8%	39%	557	0.0085	0.0925	0.0371	0.0554	40%
8	R1-008	10/28/2005	1		EOB	6.8%	28.3%	22.1%	3.3%	49%	658	0.0054	0.0858			
9	R2-008	10/28/2005	2			8.5%	36.3%	26.6%	3.6%	42%	688	0.0041	0.0836	0.0339	0.0497	41%
4	R3-008	10/30/2005	3			7.3%	30.7%	23.5%	3.1%	42%	615	0.0054	0.0829	0.0233	0.0596	28%
7	R1-007	10/27/2005	1		SLAB	7.1%	29.5%	22.8%	3.9%	55%	715	0.0048	0.0862			
7	R2-007	10/28/2005	2			7.0%	29.2%	22.6%	3.2%	46%	692	0.005	0.0832	0.0291	0.0542	35%
2	R3-007	10/28/2005	3			5.7%	23.7%	19.1%	2.2%	39%	527	0.008	0.0908	0.0442	0.0466	49%
5	R1-005	10/27/2005	1	Truck #2 + 25 gal water	SLAB	6.8%	26.7%	21.1%	3.2%	47%	639	0.0059	0.0845			
1	R2-005	10/28/2005	2			7.0%	27.6%	21.6%	2.7%	39%	577	0.0064	0.0878			
6	R3-005	10/30/2005	3			7.3%	28.7%	22.3%	3.1%	42%	701	0.005	0.0878	0.0552	0.0326	63%
6	R1-006	10/27/2005	1	Truck #3 Cement + Fiber	EOB	5.7%	23.9%	19.3%	2.3%	40%	584	0.0071	0.0906			
8	R2-006	10/28/2005	2			5.0%	20.7%	17.1%	2.1%	42%	610	0.0074	0.0865	0.0472	0.0393	55%
9	R3-006	10/30/2005	3			5.0%	21.0%	17.3%	2.1%	42%	580	0.0078	0.0930	0.0253	0.0677	27%
3	R1-003	10/27/2005	1		SLAB	5.2%	21.5%	17.7%	2.0%	38%	587	0.0076	0.0943			
6	R2-003	10/28/2005	2			4.6%	19.0%	16.0%	1.6%	35%	520	0.0091	0.0920	0.0403	0.0517	44%
1	R3-003	10/28/2005	3			3.6%	14.7%	12.8%	1.7%	47%	598	0.0088	0.0896	0.0293	0.0603	33%

FA = Fly Ash
FIBERS = Cement + Fibers
FIBERS-FA = Cement + Fly Ash + Fibers
FIBERS-FA-X = Cement + Fly Ash + Fibers + Additional Water

EOB = End of Boom
TRUCK = At Concrete Truck

The cells in red designate those with a "spacing factor" greater than 0.008 in. This is the threshold established by the Bureau of Reclamation in 1956 for "durable" (less than) vs. "non-durable" (greater than).

Appendix F – ODOT Bridge Construction Concrete Records

- Available ODOT Span 1 AA Concrete Records
- Available ODOT Span 2 HPC Cement Only Records

ODOT Span 1 AA Concrete Records

OKLAHOMA DEPARTMENT OF TRANSPORTATION

DAILY CONCRETE RECORDS

Project	IMY 40- 40-1 (74)25	**JP:**	20296(04)	**Division 5**	
Contractor	Muskogee Bridge Co.	**County**	Beckham	**Clinton Res.**	
Class	**AA/AEA/WRA**	**Produce**	Dolese Bros. Elk City, Ok	**Res. Manager**	R. Greer
For Use In:	Bridge A	**Date**	4/26/2006	**Inspector**	S. Hinds
Span	1	**Mix Desi**	**7233**		

Material	Source	Batch Quantity (1 CY) JMF	Used	Free Moisture
Portland Cement	Ash Grove, Chanute, Kansas	611	609	
Fly Ash	La Farge N.A. Amarillo,Texas	0	0	
Fine Aggregate	Kline Materials Camargo, Okla.	1396	1516	8.74 lbs
Coarse Aggregate # 67	Dolese Bros. Inc. Cooperton, Okla.	1755	1760	49.6 lbs
Coarse Aggregate 3/8 chip	Dolese Bros. Inc. Cooperton, Okla.		0	
Mixing Water	City of Elk City Elk City, Okla.	233	174	
Air Entrainment Agent	W.R. Grace Houston, Texas	3.1	6	
Mid Range Water Reducer	Master Builders inc. Houston, Texas	0	0	
Water Reducer	Master Builders Inc. Houston, Texas	18.3	18.3	
Fibermesh	SI Conc Systems Chattanooga Tenn.	0		

GREAT SEAL
1907
STAN HINDS
2288
SIGNATURE
Seal

TEST RESULTS

Ticket Number	Cubic Yard	Time Batched	Time Unloaded	Air Temp	Mix Temp	% Air	Slump	Total FA/Cement	Water Added	Total Water	W/C Ratio	Cylinder Set
39172	10.5	7:56 AM	8:56	50	67			609	0	234	0.38	
39174	10.5	8:27 AM	9:46	50	67	7.25	3	608	8	240	0.41	1 - 1D
39175	9	8:38 AM						609	0	233	0.38	
39177	10	8:54 AM	10:50					608	8	241	0.41	
Total C.Y.	**40**											

Remarks

OKLAHOMA DEPARTMENT OF TRANSPORTATION
IDENTIFICATION OF CONCRETE CYLINDERS
CONTRACT CONSTRUCTION

PROJECT IMY 40-1 (74)25 JOB PIECE 20296 (04) COUNTY Beckham

RESIDENT ENGINEER Randall Greer DIVISION 5

CONTRACTOR Muskogee Bridge Co.

CONCRETE POUR DATA

STATION LANE W/B MAINLINE OTHER

THICK 8"

IF DRAINAGE STRUCTURE, COMPLETE BELOW

STRUCTURES

NUMBER Bridge A STRUCTURAL ELEMENT Deck

SECTION SPAN 1 Design # 7233

CONCRETE MIX DATA

PRODUCER Dolese Bros. Inc LOCATION Elk City, Okla

ON SITE MIX TRANSIT MIX XXXXXXX BATCH VOLUME 10.5 CONCRETE CLASS AA/ AEA/ WRA

MATERIALS	SOURCE AND NAME	TYPE	BATCH QUANTITY	FREE MOISTURE
PORTLAND CEMENT	Ash Grove Chanute, Kansas	611 lbs	609 lbs	
FLY ASH	La Farge N.A. Amarillo, Texas	0	0	
FINE AGGREGATE	Kline Materials Camargo, Okla.	1396 lbs	1516 lbs	8.74 lbs
COARSE AGGREGATE # 67	Dolese Bros. Inc. Cooperton, Okla.	1755 lbs	1760 lbs	49.6 lbs
COARSE AGGREGATE 3/8 CHIPS	Dolese Bros. Inc. Cooperton, Okla.	0	0	
MIXING WATER	City of Elk City, Okla	233 lbs	174 lbs	
AIR ENTRAINMENT AGENT	W.R. Grace Houston, Texas	3.1oz.	6.0 oz	
WATER REDUCER	Master BuildersInc. Houston , Texas	18.3oz.	18.3 oz.	
SRA AS 20 (Tetragard)	Master BuildersInc. Houston , Texas	0	0	
FIBERMESH	SI Concrete Systems Chattanooga, Tenn.	0	0	

CYLINDER DATA

DATE CAST 4/26/2006 TIME 9:00 AM SLUMP 3 % AIR 7.25

INVOICE NUMBER 39174 MIX TEMP 67 AIR TEMP 50 W/C RATIO 0.41

WATER ADDED 8.0 lbs Total Water 240.0 lbs

METHOD OF CURE FIRST 24 HR ON SITE AFTER 24 HRS. LIME WATER SOLUTION

CYLINDER NO	1	1A	1B	1C	1D
TEST AGE	28 DAY	28 DAY	28 DAY	28 Day	28 Day

BREAK DATE 5/23/2006

CYLINDER CAST BY Stan Hinds # 2288

SIGNATURE

REMARKS

CYLINDER STRENGTH					
BREAK LOAD	129840	127750	128320	127470	134090
PSI	4592	4518	4538	4508	4743
AVG PSI	4580				

SIGNATURE

DISTRIBUTION

MATERIALS DIVISION

RES. ENG. CONTRACTOR

ODOT Span 2 HPC Cement Only Records

OKLAHOMA DEPARTMENT OF TRANSPORTATION

DAILY CONCRETE RECORDS

Project	IM 40-40-1(74)25	**JP**	20296(04)	**Division 5**	
Contractor	Muskogee Bridge Co	**County**	Beckham	**Clinton Res**	
Class	**AA High Performance**	**Producers**	Dolese Bros Elk City Ok	**Res Manager**	R Greer
For Use In	Bridge A	**Date**	4/26/2006	**Inspector**	S Hinds
Span	2	**Mix Design**	**8965**		

Material	Source	Batch Quantity (1 CY) JMF	Used	Free Moisture
Portland Cement	Ash Grove, Chanute, Kansas	574	571	
Fly Ash	La Farge N.A Amarillo,Texas	0	0	
Fine Aggregate	Kline Materials Camargo, Okla	1505	1573	71.0 lbs
Coarse Aggregate # 67	Dolese Bros. Inc. Cooperton, Okla	1285	1291	6.41 lbs
Coarse Aggregate 3/8 chip	Dolese Bros. Inc. Cooperton, Okla	345	347	1.72 lbs
Mixing Water	City of Elk City Elk City, Okla	214	134	
Air Entrainment Agent	W.R. Grace Houston, Texas	42.3	25.0 oz	
Mid Range Water Reducer	Master Builders Inc. Houston, Texas	79.5	450	
Tetragard	Master Builders Inc. Houston, Texas	13.2	13.2	
Fibermesh	SI Concrete Systems Chattanooga Tenn	0	0	

Sea

TEST RESULTS

Ticket Number	Cubic Yard	Time Batched	Time Unloaded	Air Temp	Mix Temp	% Air	Slump	Total FA/Cement	Water Added	Total Water	W/C Ratio	Cylinder Set
39178	9	9:20 AM			62	4.5					REJECTED	
39180	10.5	10:05 AM	11:25	56	62	5	1	571	0	205	0.36	
39183	9	11:07 AM									REJECTED	
39184	9	11:16 AM									REJECTED	
39186	9	11:49 AM									REJECTED	
39187	10.5	12:10 PM									REJECTED	
39191	9	1:17 PM	1:59 PM	58	65	4.5	2	571	0	214	0.37	
39192	10.5	1:41 PM	2:21 PM	62	68	5.5	3.25	572	0	214	0.37	
39194	10.5	2:10 PM	2:56 PM	68	73	5	8.25	572	0	214	0.37	
39195	9	2:20 PM	3:03 PM					572	0	213	0.37	
39196	9	2:29 PM	3:12 PM	72	76	4.5	6.5	572	0	213	0.37	1-1D
39198	10.5	2:43 PM	3:32 PM					571	0	214	0.37	
39199	10.5	3:00 PM	3:41 PM					571	0	214	0.37	
39200	10.5	3:11 PM	4:00 PM					572	0	214	0.37	
39201	10.5	3:32 PM	4:33 PM	74	80	4.75	3	571	0	213	0.37	2 - 2D
39208	10.5	4:39 PM	5:43 PM					573	0	213	0.37	
Total C.Y.	**157.5**											

Remarks Load 1 3,4 5and 6 were rejected due to Special Provision for High Performance Concrete Inspection and Testing

OKLAHOMA DEPARTMENT OF TRANSPORTATION
IDENTIFICATION OF CONCRETE CYLINDERS
CONTRACT CONSTRUCTION

PROJECT IMY 40-1 (74)25 JOB PIEC 20296 (04) COUNTY Beckham

RESIDENT ENGINEER Randall Greer DIVISION 5

CONTRACTOR Muskogee Bridge Co.

CONCRETE POUR DATA

STATION 1322+32 to 1323+35 LANE W/B MAINLINE ____ OTHER ____

THICK 8"

IF DRAINAGE STRUCTURE, COMPLETE BELOW

STRUCTURES

NUMBER Bridge A Structural Element Deck

SECTION ____ SPAN 2 Design 8965

CONCRETE MIX DATA

PRODUCEF Dolese Bros. Inc LOCATIC Elk City, Okla

ON SITE MIX ____ Transit Mix XXXXXXX BATCH VOLUME 9 CONCRETE CLASS AA High Performanc

MATERIALS	SOURCE AND NAME	TYPE	BATCH QUANTITY	FREE MOISTURE
PORTLAND CEMENT	Ash Grove Chanute, Kansas	574	571	
FINE AGGREGATE	Kline Materials Camargo, Okla.	1505	1560	71.0 lbs
COARSE AGGREGATE # 57	Dolese Bros. Inc. Cooperton, Okla.	1285	1289	6.4 lbs
COARSE AGGREGATE 3/8 CHIPS	Dolese Bros. Inc. Cooperton, Okla.	345	347	1.7 lbs
MIXING WATER	City of Elk City, Okla	214	134	
AIR ENTRAINMENT AGENT	W.R. Grace Houston, Texas	42.3	25 oz	
MID RANGE WATER REDUCER (POLYHEE	Master BuildersInc. Houston , Texas	79.5	450.0 oz	
SIKA AS 20 (Tetragard)	Master BuildersInc. Houston , Texas	13.2	13.2	

CYLINDER DATA

DATE CAST 4/26/2006 TIME 3:00 PM SLUMP 6.5 % AIR 4.5

INVOICE NUMBER 39196 MIX TEMI 76 AIR TEMP 72 W/C RATIO 0.37

WATER ADDED 0 Total Water 213 lbs

METHOD OF CURE FIRST 24 HI ON SITE AFTER 24 HRS. LIME WATER SOLUTION

CYLINDER NO	1	1A	1B	1C	1D
TEST AGE	28 DAY	28 DAY	28 DAY	28 Day	28 Day

BREAK DAT 5/23/2006 CYLINDER CAST Stan Hinds # 2288

REMARKS ____ SIGNATURE

CYLINDER STRENGTH					
BREAK LOA	186720	156740	156750	156640	156860
PSI	6604 +	5543 +	5544 +	5540 +	5548 +
AVG PSI	5756 +				

SIGNATURE

DISTRIBUTION

MATERIALS ____ DIVISION ____

RES. ENG. ____ CONTRACTOR ____

OKLAHOMA DEPARTMENT OF TRANSPORTATION
IDENTIFICATION OF CONCRETE CYLINDERS
CONTRACT CONSTRUCTION

PROJECT IMY 40-1 (74)25 JOB PIEC 20296 (04) COUNTY Beckham
RESIDENT ENGINEER Randall Greer DIVISION 5
CONTRACTOR Muskogee Bridge Co.

CONCRETE POUR DATA

STATION 1322+32 to 1323+35 LANE W/B MAINLINE OTHER
THICK 8"

IF DRAINAGE STRUCTURE, COMPLETE BELOW

STRUCTURES

NUMBER Bridge A Structural Element Deck
SECTION SPAN 2 Design 8965

CONCRETE MIX DATA

PRODUCER Dolese Bros. Inc LOCATIC Elk City, Okla
ON SITE MIX Transit Mix XXXXXXX BATCH VOLUME 9 CONCRETE CLASS AA High Performance

MATERIALS	SOURCE AND NAME	TYPE	BATCH QUANTITY	FREE MOISTURE
PORTLAND CEMENT	Ash Grove Chanute, Kansas	574	571	
FINE AGGREGATE	Kline Materials Camargo, Okla.	1505	1560	71.0 lbs
COARSE AGGREGATE # 57	Dolese Bros. Inc. Cooperton, Okla.	1285	1289	6.4 lbs
COARSE AGGREGATE 3/8 CHIPS	Dolese Bros. Inc. Cooperton, Okla.	345	347	1.7 lbs
MIXING WATER	City of Elk City, Okla	214	134	
AIR ENTRAINMENT AGENT	W.R. Grace Houston, Texas	42.3	25 oz	
MID RANGE WATER REDUCER (POLYHE	Master BuildersInc. Houston , Texas	79.5	450.0 oz	
SI...AS 20 (Tetragard)	Master BuildersInc. Houston , Texas	13.2	13.2	

CYLINDER DATA

DATE CAST 4/26/2006 TIME 3:00 PM SLUMP 6.5 % AIR 4.5
INVOICE NUMBER 39196 MIX TEMP 76 AIR TEMP 72 W/C RATIO 0.37
WATER ADDED 0 Total Water 213 lbs
METHOD OF CURE FIRST 24 HI *ON SITE* AFTER 24 HRS. LIME WATER SOLUTION

CYLINDER NO	1	1A	1B	1C	1D
TEST AGE	28 DAY	28 DAY	28 DAY	28 Day	28 Day

BREAK DAT 5/23/2006 CYLINDER CAST Stan Hinds 2288 # 2288

SIGNATURE

REMARKS

CYLINDER STRENGTH					
BREAK LOA	186720	156740	156750	156640	156860
PSI	6604 +	5543 +	5544 +	5540 +	5548 +
AVG PSI	5756 +				

SIGNATURE

DISTRIBUTION

MATERIALS DIVISION
RES. ENG. CONTRACTOR

Appendix G – Muskogee Bridge Co. Bridge Construction Concrete Records

- Available Muskogee Bridge Construction Records

Company Name
Project Name
Location

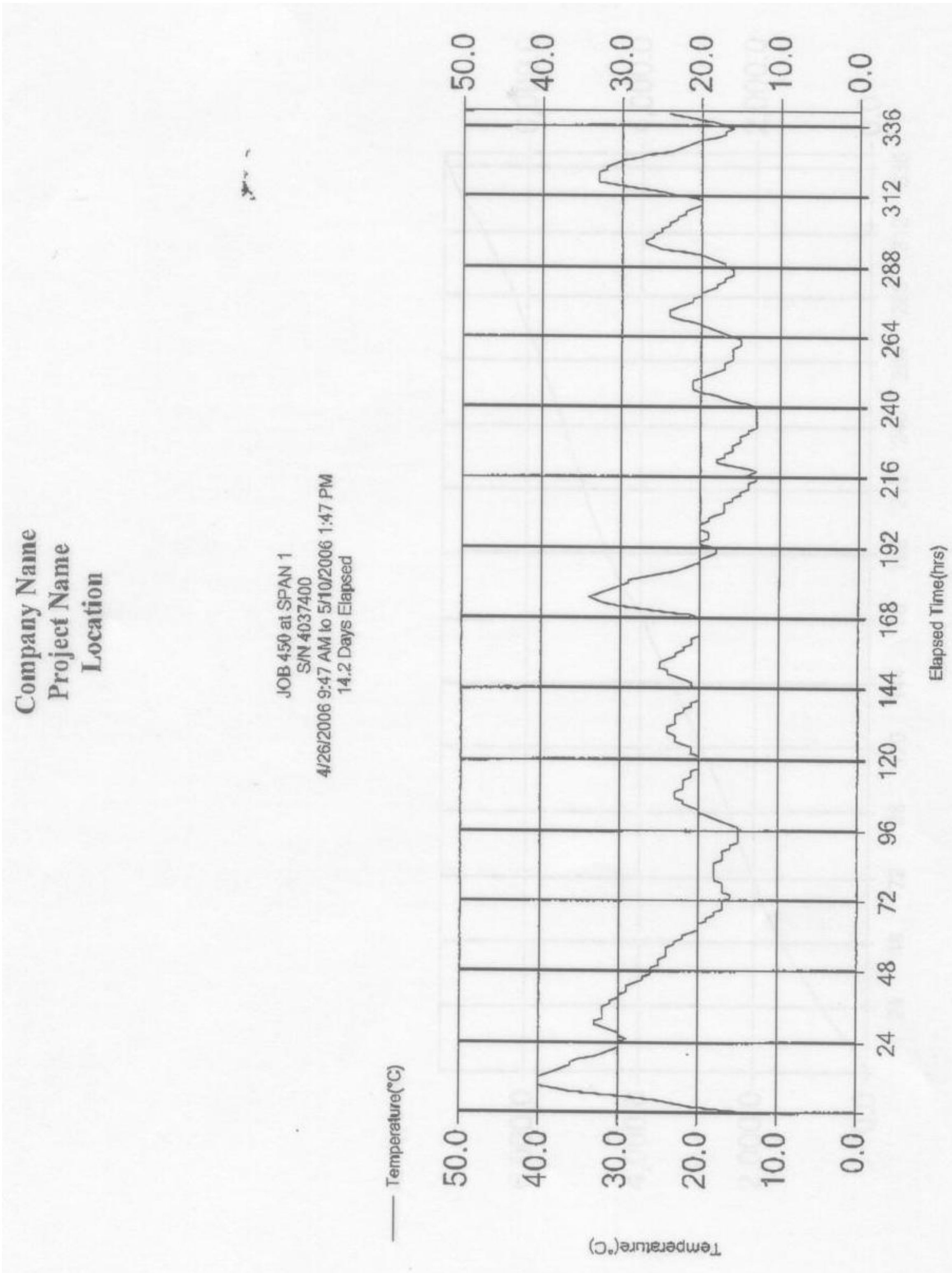
Logger	
S/N:	4037400
Job:	JOB 450
Location:	SPAN 1
Logger ID:	MAT-02-1H28D
Run State:	Locked
Start Date:	4/26/2006 9:47:55 AM
Elapsed Date (Start Date + Elapsed Time):	5/10/2006 2:13:55 PM
Elapsed Time (hrs):	340.43
Data Interval (min):	60
Number of readings:	341

Parameters

Parameter	Value
Datum (C)	0

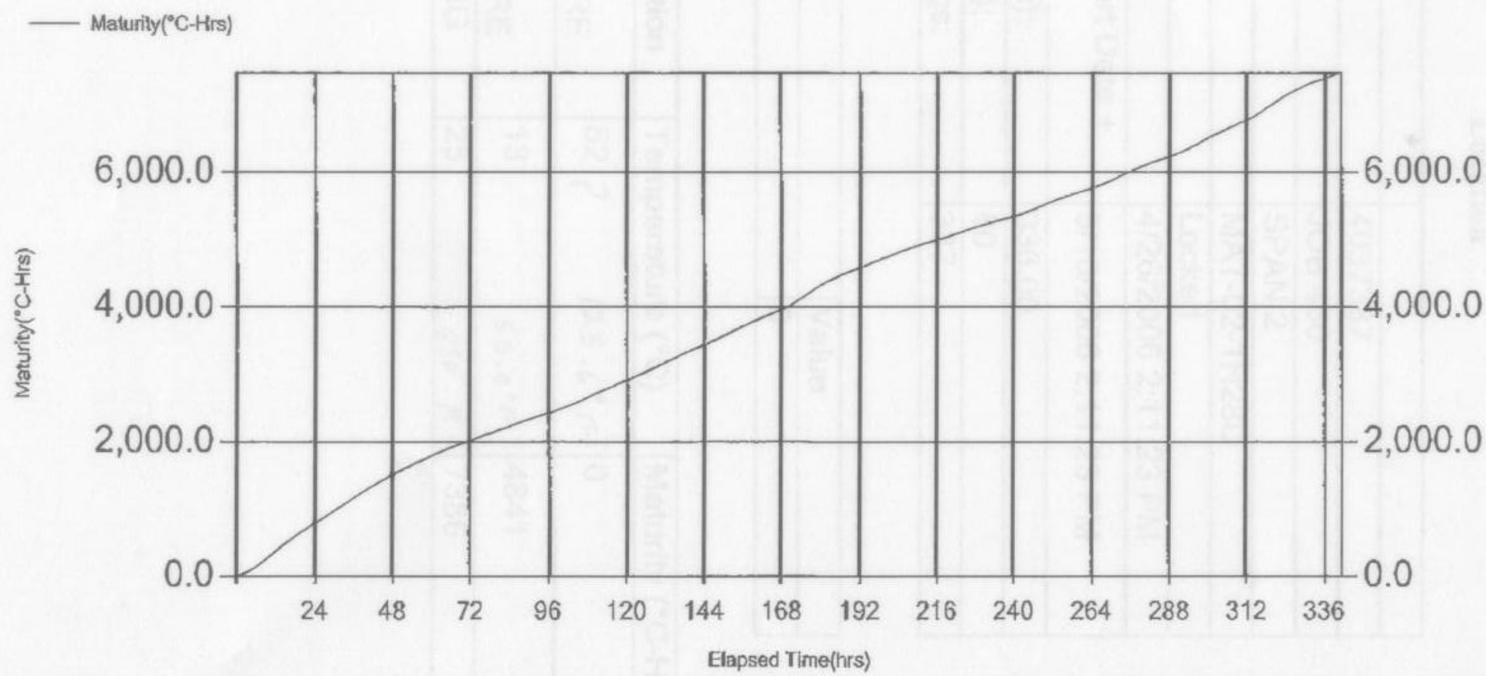
Events

Time (hrs)	Event Description	Temperature (°C)	Maturity (°C-Hrs)
8.63	MAX TEMPERATURE	40 104°F	236
214.30	MIN TEMPERATURE	13 55.4°F	4972
340.43	LAST READING	24 75.2°F	7484


Company Name
Project Name
Location
JOB 450 at SPAN 1
S/N 4037400
4/26/2006 9:47 AM to 5/10/2006 1:47 PM
14.2 Days Elapsed
Temperature(°C)
Temperature(°C)
Elapsed Time(hrs)
0.0
10.0
20.0
30.0
40.0
50.0
24
48
72
96
120
144
168
192
216
240
264
288
312
336

Company Name
Project Name
Location

JOB 450 at SPAN 1
S/N 4037400
4/26/2006 9:47 AM to 5/10/2006 1:47 PM
14.2 Days Elapsed



Company Name
Project Name
Location

Logger	
S/N:	4037387
Job:	JOB 450
Location:	SPAN 2
Logger ID:	MAT-02-1H28D
Run State:	Locked
Start Date:	4/26/2006 2:11:23 PM
Elapsed Date (Start Date + Elapsed Time):	5/10/2006 2:11:23 PM
Elapsed Time (hrs):	336.00
Data Interval (min):	60
Number of readings:	337

Parameters

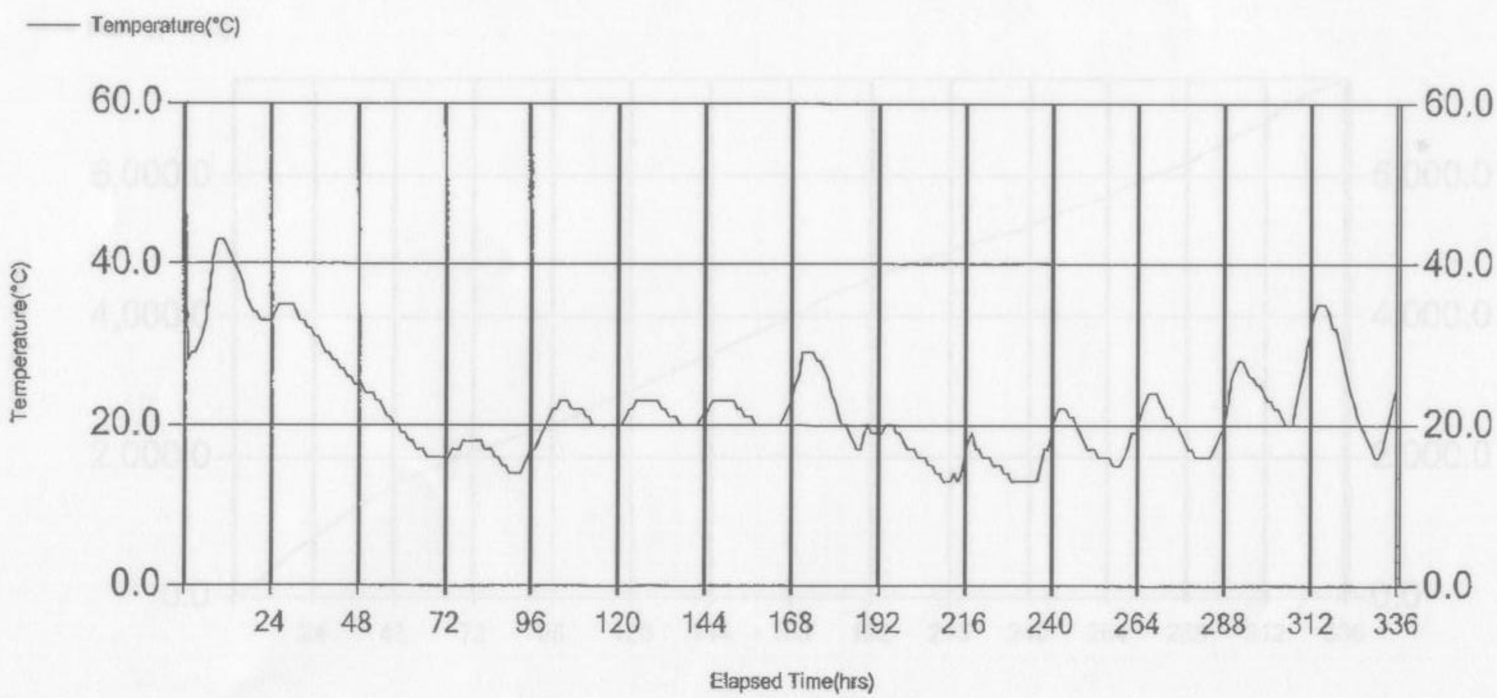
Parameter	Value
Datum (C)	0

Events

Time (hrs)	Event Description	Temperature (°C)	Maturity (°C-Hrs)
0.00	MAX TEMPERATURE	52 ? 125.6°F	0
209.68	MIN TEMPERATURE	13 55.4°F	4841
336.00	LAST READING	25 77° F	7386

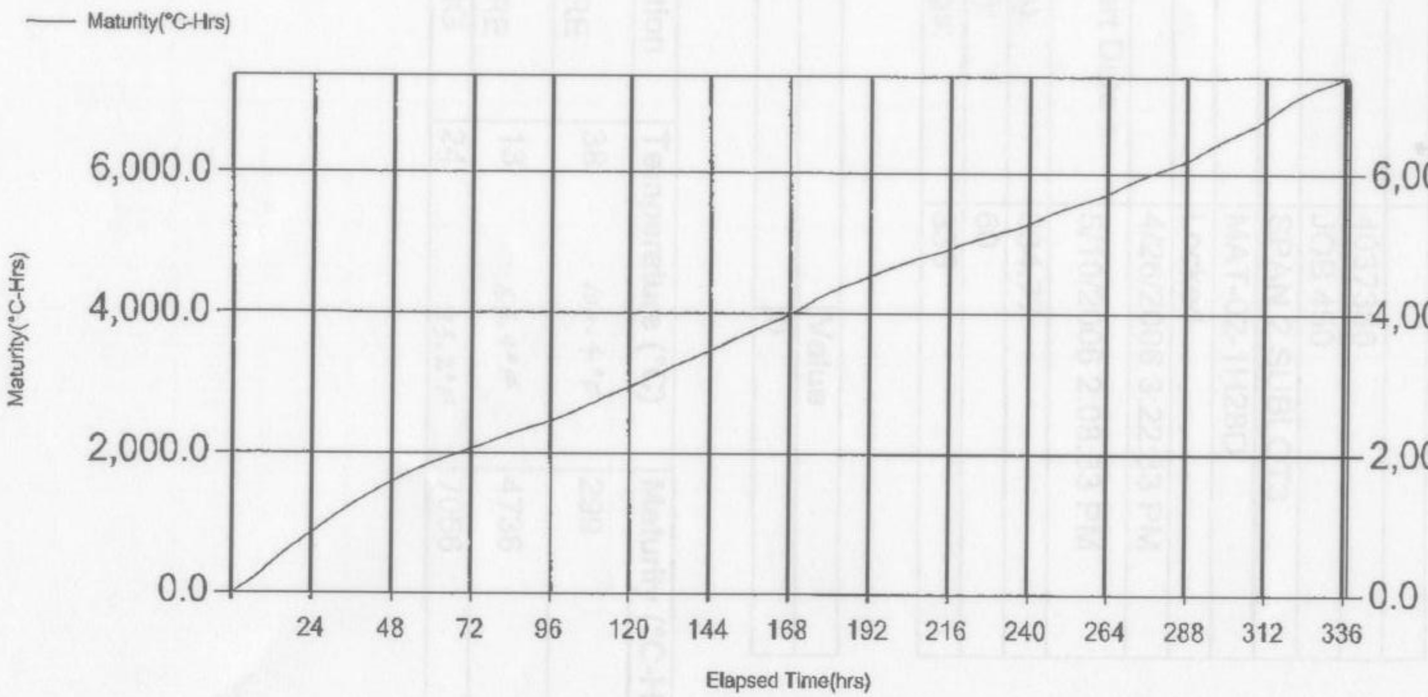
Company Name
Project Name
Location

JOB 450 at SPAN 2
S/N 4037387
4/26/2006 2:11 PM to 5/10/2006 2:11 PM
14.0 Days Elapsed



Company Name
Project Name
Location

JOB 450 at SPAN 2
S/N 4037387
4/26/2006 2:11 PM to 5/10/2006 2:11 PM
14.0 Days Elapsed



Company Name
Project Name
Location

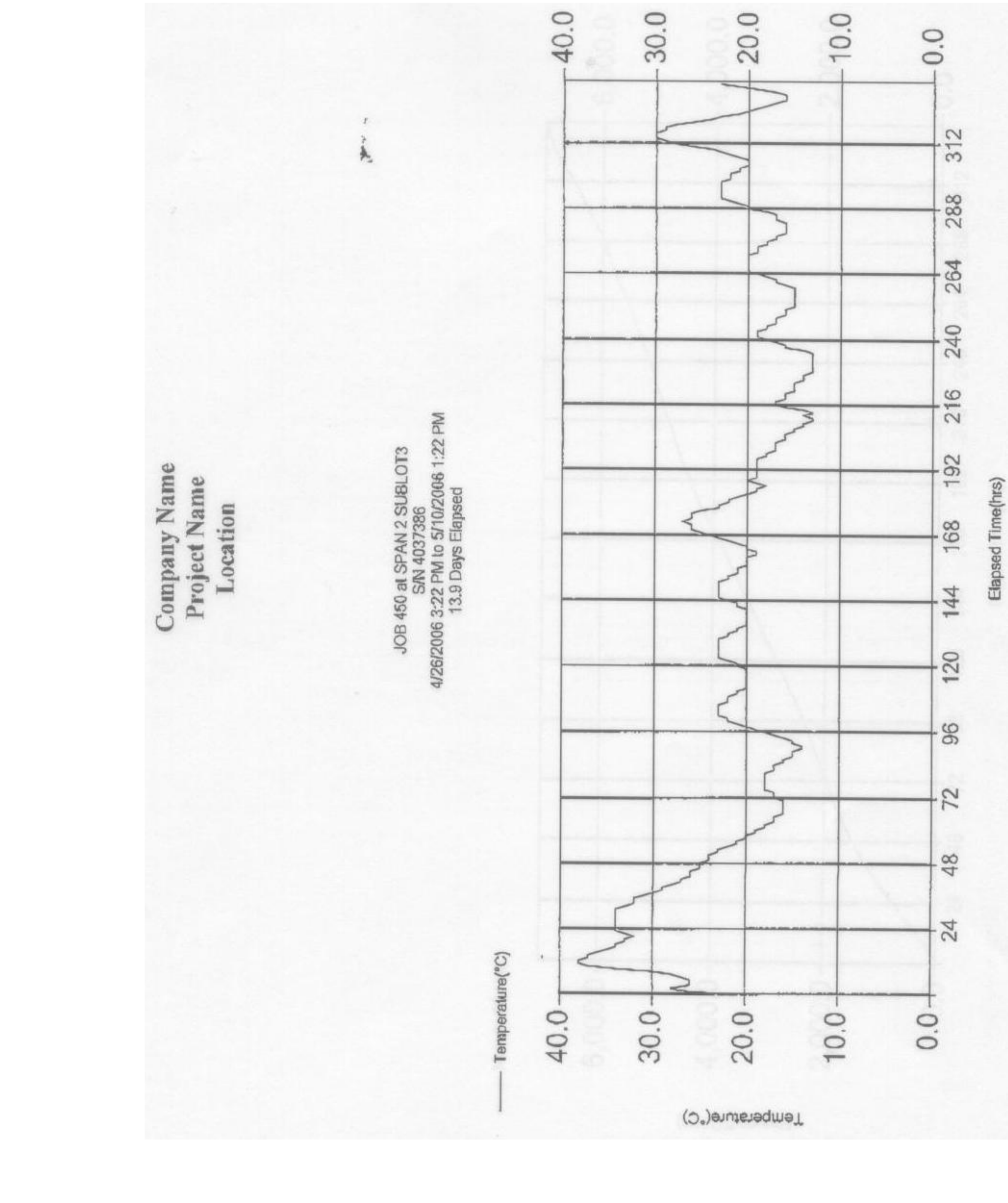
Logger	
S/N:	4037386
Job:	JOB 450
Location:	SPAN 2 SUBLOT3
Logger ID:	MAT-02-1H28D
Run State:	Locked
Start Date:	4/26/2006 3:22:33 PM
Elapsed Date (Start Date + Elapsed Time):	5/10/2006 2:08:33 PM
Elapsed Time (hrs):	334.77
Data Interval (min):	60
Number of readings:	335

Parameters

Parameter	Value
Datum (C)	0

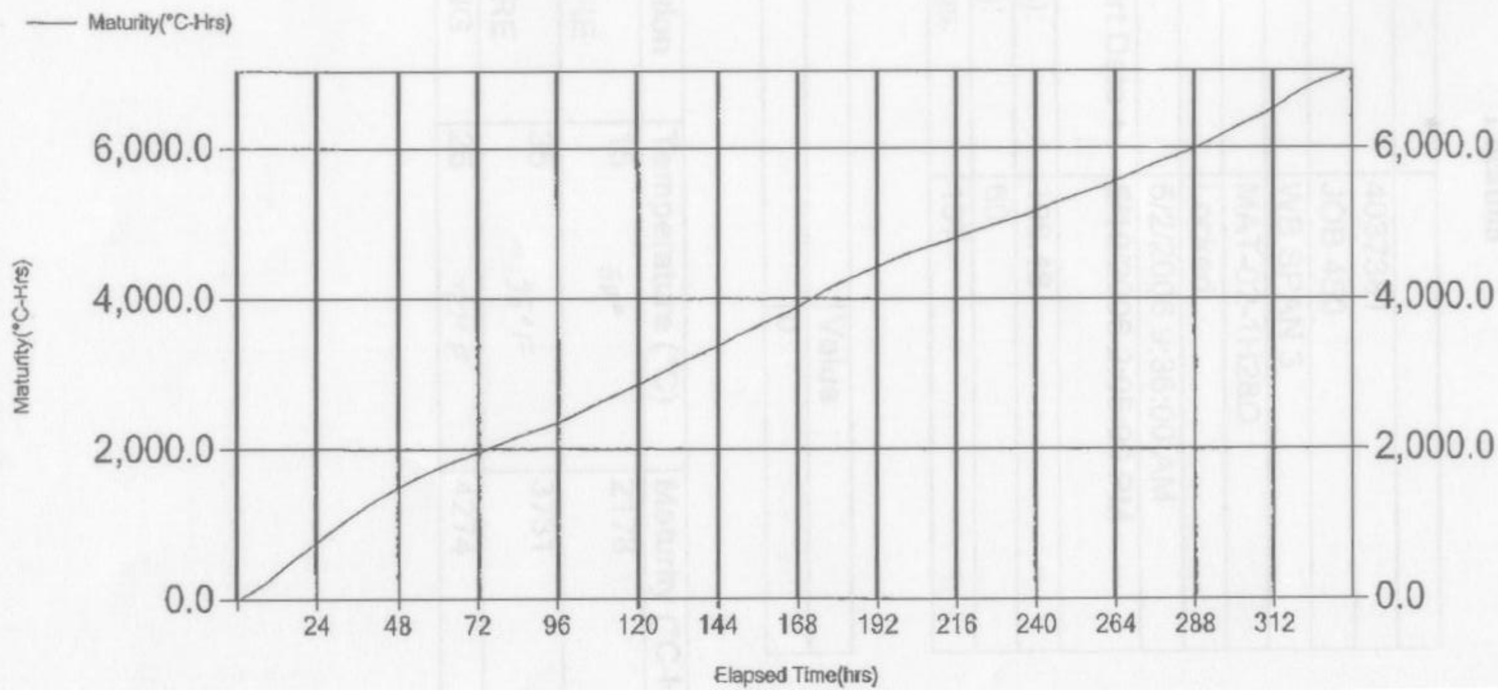
Events

Time (hrs)	Event Description	Temperature (°C)	Maturity (°C-Hrs)
10.43	MAX TEMPERATURE	38 100.4°F	299
209.88	MIN TEMPERATURE	13 55.4°F	4736
334.77	LAST READING	24 75.2°F	7056


Company Name
Project Name
Location
JOB 450 at SPAN 2 SUBLOT3
S/N 4037386
4/26/2006 3:22 PM to 5/10/2006 1:22 PM
13.9 Days Elapsed
Temperature(°C)
Elapsed Time(hrs)

Company Name
Project Name
Location

JOB 450 at SPAN 2 SUBLOT3
S/N 4037386
4/26/2006 3:22 PM to 5/10/2006 1:22 PM
13.9 Days Elapsed



Company Name
Project Name
Location

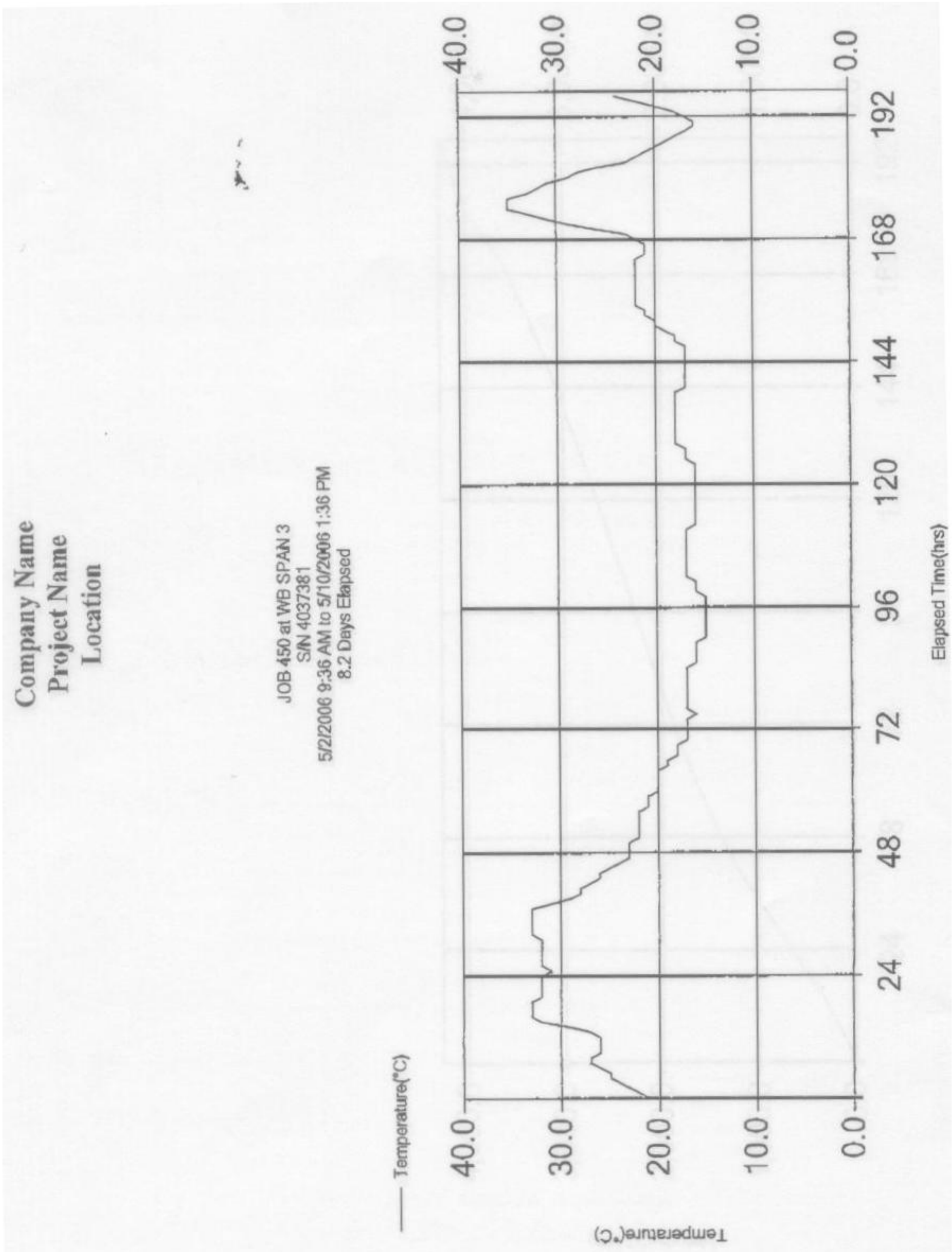
Logger	
S/N:	4037381
Job:	JOB 450
Location:	WB SPAN 3
Logger ID:	MAT-02-1H28D
Run State:	Locked
Start Date:	5/2/2006 9:36:00 AM
Elapsed Date (Start Date + Elapsed Time):	5/10/2006 2:05:00 PM
Elapsed Time (hrs):	196.48
Data Interval (min):	60
Number of readings:	197

Parameters

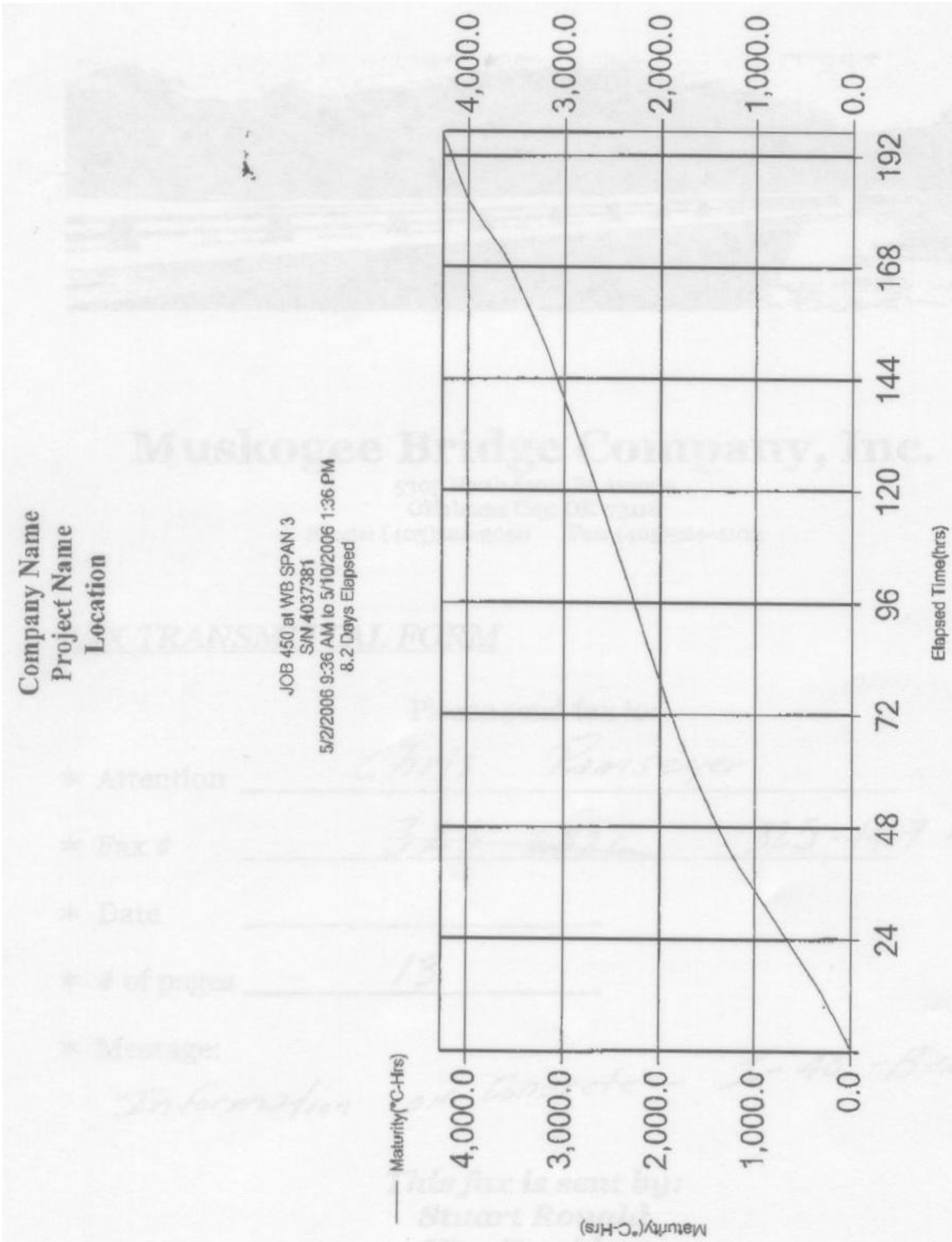
Parameter	Value
Datum (C)	0

Events

Time (hrs)	Event Description	Temperature (°C)	Maturity (°C-Hrs)
89.90	MIN TEMPERATURE	15 59°	2178
173.83	MAX TEMPERATURE	35 95°F	3731
196.48	LAST READING	25 77°F	4274



Company Name
Project Name
Location
JOB 450 at WB SPAN 3
S/N 4037381
5/2/2006 9:36 AM to 5/10/2006 1:36 PM
8.2 Days Elapsed
Temperature(°C)
Temperature(°C)
40.0
30.0
20.0
10.0
0.0
24
48
72
96
120
144
168
192
Elapsed Time(hrs)


Company Name
Project Name
Location
JOB 450 at WB SPAN 3
S/N 4037381
5/2/2006 9:36 AM to 5/10/2006 1:36 PM
8.2 Days Elapsed
Maturity(°C-Hrs)
Maturity(°C-Hrs)
0.0
1,000.0
2,000.0
3,000.0
4,000.0
24
48
72
96
120
144
168
192
Elapsed Time(hrs)

Appendix H – Muskogee Bridge Co. Bridge Construction Concrete Data Sheets

- Available Muskogee Bridge Concrete Data Sheets

MUSKOGEE BRIDGE COMPANY, INC.

CONCRETE CYLINDER TEST REPORT

DATE CAST: 4-26-2006

PROJECT: IMY-40-1 (074) 025 & IBR-105N (108) IB

ELEMENT TESTED: SPAN 1

CUBIC YARDS IN ELEMENT: 10.5 @ 21

WEATHER: CLEAR & WINDY

CONCRETE MIX: AA, A/E, DOLESE MIX CODE 7233

CONCRETE TICKET#: 39174

AMBIENT TEMPERATURE: 50 F CONCRETE TEMPERATURE: 67 F

AIR CONTENT: 6.4 % SLUMP: 3" UNIT WEIGHT: 143.1 LBS/

Cylinder I.D.	Age @ Break	Compressive Strength(PSI)	Average
1A	7	3560	
1B	7	3610	3585
1C	28	0	
1D	28	0	0

7 DAY BREAK: 5-3-2006
28 DAY BREAK: 5-24-2006

MUSKOGEE BRIDGE COMPANY, INC.

CONCRETE CYLINDER TEST REPORT

DATE CAST: 4-26-2006

PROJECT: IMY-40-1 (074) 025 & IBR-105N (108) IB

ELEMENT TESTED: SPAN 2

CUBIC YARDS IN ELEMENT: 10.5 @ 21

WEATHER: CLEAR WITH LIGHT WINDS

CONCRETE MIX: AA, A/E, HP, DOLESE MIX CODE 8965

CONCRETE TICKET#:

AMBIENT TEMPERATURE: 70 F CONCRETE TEMPERATURE: 76 F

AIR CONTENT: 5 % SLUMP: 5.5" UNIT WEIGHT: N/A

Cylinder I.D.	Age @ Break	Compressive Strength(PSI)	Average
A	7	NO CYLINDER MADE ON THIS TEST	
B	7	0	0
C	28	0	
D	28	0	0

7 DAY BREAK: 5-3-2006
28 DAY BREAK: 5-24-2006

MUSKOGEE BRIDGE COMPANY, INC.

CONCRETE CYLINDER TEST REPORT

DATE CAST: 4-26-2006

PROJECT: IMY-40-1 (074) 025 & IBR-105N (108) IB

ELEMENT TESTED: SPAN 2

CUBIC YARDS IN ELEMENT: 10.5 @ 31.5

WEATHER: CLEAR WITH LIGHT WINDS

CONCRETE MIX: AA, A/E, HP, DOLESE MIX CODE 8965

CONCRETE TICKET#:

AMBIENT TEMPERATURE: 71 F CONCRETE TEMPERATURE: 77 F

AIR CONTENT: 5.5 % SLUMP: 9" UNIT WEIGHT: N/A

Cylinder I.D.	Age @ Break	Compressive Strength(PSI)	Average
A	7	NO CYLINDER MADE ON THIS TEST	
B	7	0	0
C	28	0	
D	28	0	0

7 DAY BREAK: 5-3-2006
28 DAY BREAK: 5-24-2006

MUSKOGEE BRIDGE COMPANY, INC.

CONCRETE CYLINDER TEST REPORT

DATE CAST: 4-26-2006

PROJECT: IMY-40-1 (074) 025 & IBR-105N (108) IB

ELEMENT TESTED: SPAN 2

CUBIC YARDS IN ELEMENT: 9 @ 115.50

WEATHER: CLEAR WITH LIGHT WINDS

CONCRETE MIX: AA, A/E, HP, DOLESE MIX CODE 8965

CONCRETE TICKET#: 39196

AMBIENT TEMPERATURE: 72 F CONCRETE TEMPERATURE: 76 F

AIR CONTENT: 5.4 % SLUMP: 7.5" UNIT WEIGHT: 145.8LBS/

Cylinder I.D.	Age @ Break	Compressive Strength(PSI)	Average
2A	7	6610	
2B	7	6790	6700
2C	28	0	
2D	28	0	0

7 DAY BREAK: 5-3-2006
28 DAY BREAK: 5-24-2006

MUSKOGEE BRIDGE COMPANY, INC.

CONCRETE CYLINDER TEST REPORT

DATE CAST: 4-26-2006

PROJECT: IMY-40-1 (074) 025 & IBR-105N (108) IB

ELEMENT TESTED: SPAN 2

CUBIC YARDS IN ELEMENT: 10.5 @ 157.50

WEATHER: CLEAR WITH LIGHT WINDS

CONCRETE MIX: AA, A/E, HP, DOLESE MIX CODE 8965

CONCRETE TICKET#: 39201

AMBIENT TEMPERATURE: 74 F   CONCRETE TEMPERATURE: 80 F

AIR CONTENT: 5 %   SLUMP: 5.5"   UNIT WEIGHT: 146.6LBS/

Cylinder I.D.	Age @ Break	Compressive Strength(PSI)	Average
3A	7	0	
3B	7	0	0
3C	28	0	
3D	28	0	0

7 DAY BREAK: 5-3-2006
28 DAY BREAK: 5-24-2006

MUSKOGEE BRIDGE COMPANY, INC.

CONCRETE CYLINDER TEST REPORT

DATE CAST: 4-26-2006

PROJECT: IMY-40-1 (074) 025 & IBR-105N (108) IB

ELEMENT TESTED: SPAN 2

CUBIC YARDS IN ELEMENT: 10.5 @ 10.5

WEATHER: CLEAR WITH LIGHT WINDS

CONCRETE MIX: AA, A/E, HP, DOLESE MIX CODE 8965

CONCRETE TICKET#: 39291

AMBIENT TEMPERATURE: 66 F CONCRETE TEMPERATURE: 70 F

AIR CONTENT: 4 % SLUMP: 1.5" UNIT WEIGHT: N/A

Cylinder I.D.	Age @ Break	Compressive Strength(PSI)	Average
A	7	NO CYLINDER MADE ON THIS TEST	
B	7	0	0
C	28	0	
D	28	0	0

7 DAY BREAK: 5-3-2006
28 DAY BREAK: 5-24-2006

MUSKOGEE BRIDGE COMPANY, INC.

CONCRETE CYLINDER TEST REPORT

DATE CAST: 5-2-2006

PROJECT: IMY-40-1 (074) 025 & IBR-105N (108) IB

ELEMENT TESTED: SPAN 3

CUBIC YARDS IN ELEMENT: 4 @ 4

WEATHER: MOSTLY CLEAR & WINDY

CONCRETE MIX: AA, A/E, HP WITH FIBERS, DOLESE MIX CODE 8994

CONCRETE TICKET#: 39291

AMBIENT TEMPERATURE: 65 F CONCRETE TEMPERATURE: 71 F

AIR CONTENT: 7 % SLUMP: 4.25" UNIT WEIGHT: 143.5LBS/

Cylinder I.D.	Age @ Break	Compressive Strength(PSI)	Average
4A	7	0	
4B	7	0	0
4C	28	0	
4D	28	0	0

7 DAY BREAK: 5-9-2006
28 DAY BREAK: 5-30-2006

MUSKOGEE BRIDGE COMPANY, INC.

CONCRETE CYLINDER TEST REPORT

DATE CAST: 5-2-2006

PROJECT: IMY-40-1 (074) 025 & IBR-105N (108) IB

ELEMENT TESTED: SPAN 3

CUBIC YARDS IN ELEMENT: 10.5 @ 18.5

WEATHER: CLOUDY & WINDY

CONCRETE MIX: AA, A/E, HP WITH FIBERS, DOLESE MIX CODE 8994

CONCRETE TICKET#: 39295

AMBIENT TEMPERATURE: 65 F CONCRETE TEMPERATURE: 74 F

AIR CONTENT: 7.6 % SLUMP: 5" UNIT WEIGHT: N/A

Cylinder I.D.	Age @ Break	Compressive Strength(PSI)	Average
A	7	NO CYLINDER MADE ON THIS TEST	
B	7	0	0
C	28	0	
D	28	0	0

7 DAY BREAK: 5-9-2006
28 DAY BREAK: 5-30-2006

MUSKOGEE BRIDGE COMPANY, INC.

CONCRETE CYLINDER TEST REPORT

DATE CAST: 5-2-2006

PROJECT: IMY-40-1 (074) 025 & IBR-105N (108) IB

ELEMENT TESTED: SPAN 3

CUBIC YARDS IN ELEMENT: 10.5 @ 29.00

WEATHER: CLOUDY & WINDY

CONCRETE MIX: AA, A/E, HP WITH FIBERS, DOLESE MIX CODE 8994

CONCRETE TICKET#: 39297

AMBIENT TEMPERATURE: 66 F CONCRETE TEMPERATURE: 76 F

AIR CONTENT: 7.6 % SLUMP: 5" UNIT WEIGHT: N/A

Cylinder I.D.	Age @ Break	Compressive Strength(PSI)	Average
A	7	NO CYLINDER MADE ON THIS TEST	
B	7	0	0
C	28	0	
D	28	0	0

7 DAY BREAK: 5-9-2006
28 DAY BREAK: 5-30-2006

Appendix I – Batch Tickets

- Available Tickets of Rejected Batches
- Available Tickets of Batches Used

Rejected Batch Tickets

DOLESE

A SYMBOL OF QUALITY
A SYMBOL OF SERVICE

105 E. 7TH STREET • BOX 390 • ELK CITY, OK 73648-0390
PHONE (580) 225-1247

0588

SOLD TO		TIME	DATE	TICKET NO.
MUSKOGEE BRIDGE CO INC	MUS350	09:20	04/26/2006	39180

DELIVER TO	DUE ON JOB	TRAVEL	SECTION	ORDER NO.	QUANTITY ORDERED
IMY-40-1(074)025.				57450	105.00

DIRECTIONS	PLANT	TRUCK	DRIVER	QUANTITY SHIPPED
I-40 AT 1ST SAYRE EXIT	M-72	528	J CHARTNEY	9.00

	CONTRACT OR P.O.	JOB NO.	CHG.	CASH	C.O.D.
3.00		55348	X		

QUANTITY	UNIT	DESCRIPTION	CODE	PRICE	EXTENSION
9.00	yd	CONTRACTOR MIX NO GUARANTEE	8965		
	119 oz	Tetragaard			

WATER ADDED	ESTIMATED SLUMP		1	2	3	4	5	6	7	8	9	CYLINDERS MADE
		BEFORE WATER ADDED	25	50	75	100	125	150	180	205	230	
REQUESTED BY		AFTER WATER ADDED	1	2	3	4	5	6	7	8	9	CYLINDERS MADE

LEFT PLANT	ARRIVED JOB	START UNLOADING	FINISH UNLOADING	LEFT JOB	ARRIVED PLANT
9:53	10:13	⊖	⊖	11:17	

SUB TOTAL	
SALES TAX	
DELIVERY CHARGE	
HOLDING	
TICKET TOTAL	
JOB TOTAL	

ADDITIONAL TERMS OF SALE ON REVERSE SIDE OF TICKET

If buyer requests seller to make delivery across street curb, buyer agrees to be responsible for all damage done as a result thereof, including, but not limited to, damage to sidewalks, driveways, and grounds. Buyer agrees to indemnify, defend, and hold harmless seller in the event a claim is made against seller from damage arising from such actions.

Received above material in good condition.

Signature ____________ Signature X ____________

CAUTION! SEE REVERSE OF TICKET FOR WARNING INFORMATION

CONTROL NO.. 39178

M-72 09:20 TRUCK # 528 TKT ID 55348 LD ID 57450

MATERIAL	REQUIRED	BATCHED	%MOISTURE	ACTUAL WAT
CEMENT	5166 lb	5145		
WATER	162.1 gl	162.0		162.00 gl
#57	11623 lb	11620	0.500% M	6.93 gl
#8	3121 lb	3120	0.500% M	1.86 gl
SAND	14049 lb	14040	3.722% A	60.38 gl
AEA	54.0 oz	54.0		
MRWRA	715.5 oz	715.0		

NON-SIMULATED NUM BATCHES: 2

FORM NO.
6024

A SYMBOL OF QUALITY
A SYMBOL OF SERVICE

CUSTOMER

DOLESE

105 E. 7TH STREET • BOX 390 • ELK CITY, OK 73648-0390
PHONE (580) 225-1247

0588

SOLD TO			TIME	DATE	TICKET NO.
MUSKOGEE BRIDGE CO INC	MUS350		11:07	04/26/2006	39185

DELIVER TO	DUE ON JOB	TRAVEL	SECTION	ORDER NO.	QUANTITY ORDERED
IMY-40-1(074)085.				57455	105.00

DIRECTIONS	PLANT	TRUCK	DRIVER	QUANTITY SHIPPED
I-40 AT 1ST SAYRE EXIT	M-72	994	R HOLFELDT	28.50

	CONTRACT OR P.O.	JOB NO.	CHG.	CASH	C.O.D.
3.00		55354	X		

QUANTITY	UNIT	DESCRIPTION	CODE	PRICE	EXTENSION
9.00	yd	CONTRACTOR MIX NO GUARANTEE	8965		

	ESTIMATED SLUMP											
WATER ADDED	BEFORE WATER ADDED	1	2	3	4	5	6	7	8	9	CYLINDERS MADE	
		25	50	75	100	125	150	180	205	230		
REQUESTED BY	AFTER WATER ADDED	1	2	3	4	5	6	7	8	9	CYLINDERS MADE	SUB TOTAL

LEFT PLANT	ARRIVED JOB	START UNLOADING	FINISH UNLOADING	LEFT JOB	ARRIVED PLANT	SALES TAX
11:21	1141	11:43	1:20			

ADDITIONAL TERMS OF SALE ON REVERSE SIDE OF TICKET

If buyer requests seller to make delivery across street curb, buyer agrees to be responsible for all damage done as a result thereof, including, but not limited to, damage to sidewalks, driveways, and grounds. Buyer agrees to indemnify, defend, and hold harmless seller in the event a claim is made against seller from damage arising from such actions.

Received above material in good condition.

Signature ____________ Signature ____________

DELIVERY CHARGE	
HOLDING	
TICKET TOTAL	
JOB TOTAL	

CAUTION! SEE REVERSE OF TICKET FOR WARNING INFORMATION

CONTROL NO. 39183

M-72 11:07 TRUCK # 994 TKT ID 55354 LD ID 57455

MATERIAL	REQUIRED	BATCHED	%MOISTURE	ACTUAL WAT
CEMENT	5166 lb	5145		
WATER	143.2 gl	144.0		144.00 gl
#57	11623 lb	11600	0.500% M	6.92 gl
#8	3121 lb	3120	0.500% M	1.86 gl
SAND	14132 lb	14120	4.331% A	70.24 gl
AEA	~~34.0 oz~~	~~34.0~~		
HRWRA	715.5 oz	716.0		

NON-SIMULATED NUM BATCHES: 2

39183

CUSTOMER

FORM NO. 6024

A SYMBOL OF QUALITY
A SYMBOL OF SERVICE

DOLESE

105 E. 7TH STREET • BOX 390 • ELK CITY, OK 73648-0390
PHONE (580) 225-1247

0588

SOLD TO		TIME	DATE	TICKET NO.
MUSKOGEE BRIDGE CO INC	MUS350	11:16	04/26/2006	39184

DELIVER TO	DUE ON JOB	TRAVEL	SECTION	ORDER NO.	QUANTITY ORDERED
IMY-40-1(074)025.				57457	105.00

DIRECTIONS	PLANT	TRUCK	DRIVER	QUANTITY SHIPPED
I-40 AT 1ST SAYRE EXIT	M-72	499	J BENNETT	37.50

	CONTRACT OR P.O.	JOB NO.	CHG.	CASH	C.O.D.
3.00		55355	X		

QUANTITY	UNIT	DESCRIPTION	CODE	PRICE	EXTENSION
9.00	yd	CONTRACTOR MIX NO GUARANTEE	8965		

WATER ADDED	ESTIMATED SLUMP										
	BEFORE WATER ADDED	1	2	3	4	5	6	7	8	9	CYLINDERS MADE 0
REQUESTED BY		25	50	75	100	125	150	180	205	230	
	AFTER WATER ADDED	1	2	3	4	5	6	7	8	9	CYLINDERS MADE

LEFT PLANT	ARRIVED JOB	START UNLOADING	FINISH UNLOADING	LEFT JOB	ARRIVED PLANT
1128	1149	1154			

SUB TOTAL	
SALES TAX	
DELIVERY CHARGE	
HOLDING	
TICKET TOTAL	
JOB TOTAL	

ADDITIONAL TERMS OF SALE ON REVERSE SIDE OF TICKET

If buyer requests seller to make delivery across street curb, buyer agrees to be responsible for all damage done as a result thereof, including, but not limited to, damage to sidewalks, driveways, and grounds. Buyer agrees to indemnify, defend, and hold harmless seller in the event a claim is made against seller from damage arising from such actions.

Received above material in good condition.

Signature ____________ Signature ____________

CAUTION! SEE REVERSE OF TICKET FOR WARNING INFORMATION

CONTROL NO. 39184

M-72 11:16 TRUCK # 499 TKT ID 55355 LD ID 57457

MATERIAL	REQUIRED	BATCHED	%MOISTURE	ACTUAL WAT
CEMENT	5166 lb	5145		
WATER	142.5 gl	142.0		142.00 gl
#57	11623 lb	11600	0.500% M	6.92 gl
#8	3121 lb	3120	0.500% M	1.86 gl
SAND	14138 lb	14120	4.377% A	70.95 gl
AEA	56.0 oz	56.0		
MRWRA	715.5 oz	714.0		

NON-SIMULATED NUM BATCHES: 2

Too Dry

4½ Slump @ truck

Batch Tickets

CUSTOMER

FORM NO. 6024

A SYMBOL OF QUALITY
A SYMBOL OF SERVICE

DOLESE

105 E. 7TH STREET • BOX 390 • ELK CITY, OK 73648-0390
PHONE (580) 225-1247

0588

SOLD TO		TIME	DATE	TICKET NO.
MUSKOGEE BRIDGE CO INC	MUS350	07:56	04/26/2006	39174

DELIVER TO	DUE ON JOB	TRAVEL	SECTION	ORDER NO.	QUANTITY ORDERED
IMY-40-1(074)025.				57444	40.00

DIRECTIONS	PLANT	TRUCK	DRIVER	QUANTITY SHIPPED
I-40 AT 1ST SAYRE EXIT	M-72	669	S. POST	10.50

	CONTRACT OR P.O.	JOB NO.	CHG.	CASH	C.O.D.
3.00		55342	X		

QUANTITY	UNIT	DESCRIPTION	CODE	PRICE	EXTENSION
10.50	yd	CLASS AA AEA/WRA	7233		

	ESTIMATED SLUMP		1	2	3	4	5	6	7	8	9	
WATER ADDED		BEFORE WATER ADDED	25	50	75	100	125	150	180	205	230	CYLINDERS MADE
REQUESTED BY		AFTER WATER ADDED	1	2	3	4	5	6	7	8	9	CYLINDERS MADE

LEFT PLANT	ARRIVED JOB	START UNLOADING	FINISH UNLOADING	LEFT JOB	ARRIVED PLANT

SUB TOTAL	
SALES TAX	
DELIVERY CHARGE	
HOLDING	
TICKET TOTAL	
JOB TOTAL	

ADDITIONAL TERMS OF SALE ON REVERSE SIDE OF TICKET

If buyer requests seller to make delivery across street curb, buyer agrees to be responsible for all damage done as a result thereof, including, but not limited to, damage to sidewalks, driveways, and grounds. Buyer agrees to indemnify, defend, and hold harmless seller in the event a claim is made against seller from damage arising from such actions.

Received above material in good condition.

Signature ____________ Signature ____________

CAUTION! SEE REVERSE OF TICKET FOR WARNING INFORMATION

CONTROL NO. 39172

M-72 07:56 TRUCK # 669 TKT ID 55342 LD ID 57444

MATERIAL	REQUIRED	BATCHED	%MOISTURE	ACTUAL WAT
CEMENT	6416 lb	6390		
467	18520 lb	18500	0.500% M	11.03 gl
SAND	15080 lb	15060	2.090% A	50.52 gl
WATER	232.4 gl	233.0		233.00 gl
AEA	63.0 oz	63.0		
WRA	192.1 oz	192.0		

NON-SIMULATED NUM BATCHES: 2

SLUMP: 3.00 "

FORM NO. 6024

A SYMBOL OF QUALITY
A SYMBOL OF SERVICE

CUSTOMER

DOLESE

105 E. 7TH STREET • BOX 390 • ELK CITY, OK 73648-0390
PHONE (580) 225-1247

0588

SOLD TO		TIME	DATE	TICKET NO.
MUSKOGEE BRIDGE CO INC	MUS350	08:27	04/26/2006	39176

DELIVER TO	DUE ON JOB	TRAVEL	SECTION	ORDER NO.	QUANTITY ORDERED
IMY-40-1(074)025.				57446	40.00

DIRECTIONS	PLANT	TRUCK	DRIVER	QUANTITY SHIPPED
I-40 AT 1ST SAYRE EXIT	M-72	670	R. WADDLE	21.00

	CONTRACT OR P.O.	JOB NO.	CHG.	CASH	C.O.D.
3.00		55344	X		

QUANTITY	UNIT	DESCRIPTION	CODE	PRICE	EXTENSION
10.50	yd	CLASS AA AEA/WRA	7233		

WATER ADDED	ESTIMATED SLUMP		1	2	3	4	5	6	7	8	9	CYLINDERS MADE
10		BEFORE WATER ADDED	1	2	3	4	5	6	7	8	9	0
			25	50	75	100	125	150	180	205	230	
REQUESTED BY		AFTER WATER ADDED	1	2	3 /	4	5	6	7	8	9	0

LEFT PLANT	ARRIVED JOB	START UNLOADING	FINISH UNLOADING	LEFT JOB	ARRIVED PLANT
845	913	9:27	9:46		

SUB TOTAL	
SALES TAX	
DELIVERY CHARGE	
HOLDING	
TICKET TOTAL	
JOB TOTAL	

ADDITIONAL TERMS OF SALE ON REVERSE SIDE OF TICKET

If buyer requests seller to make delivery across street curb, buyer agrees to be responsible for all damage done as a result thereof, including, but not limited to, damage to sidewalks, driveways, and grounds. Buyer agrees to indemnify, defend, and hold harmless seller in the event a claim is made against seller from damage arising from such actions.

Received above material in good condition.

Signature ______ Signature Pump

CAUTION! SEE REVERSE OF TICKET FOR WARNING INFORMATION

CONTROL NO.. 39174

M-72 08:27 TRUCK # 670 TKT ID 55344 LD ID 57446

MATERIAL	REQUIRED	BATCHED	%MOISTURE	ACTUAL WAT
CEMENT	6416 lb	6385		
#67	18520 lb	18480	0.500% M	11.02 gl
SAND	15181 lb	15160	3.567% A	62.57 gl
WATER	220.3 gl	219.0		219.00 gl
AEA	63.0 oz	63.0		
WRA	192.1 oz	192.0		

NON-SIMULATED NUM BATCHES: 2

SLUMP: 3.00 "

FORM NO. 6024

A SYMBOL OF QUALITY
A SYMBOL OF SERVICE

CUSTOMER

DOLESE

105 E. 7TH STREET • BOX 390 • ELK CITY, OK 73648-0390
PHONE (580) 225-1247

0588

SOLD TO		TIME	DATE	TICKET NO.
MUSKOGEE BRIDGE CO INC	MUS350	08:38	04/26/2006	39177

DELIVER TO	DUE ON JOB	TRAVEL	SECTION	ORDER NO.	QUANTITY ORDERED
IMY-40-1(074)025.				57447	40.00

DIRECTIONS	PLANT	TRUCK	DRIVER	QUANTITY SHIPPED
I-40 AT 1ST SAYRE EXIT	M-72	499	Jack Barnett	30.00

	CONTRACT OR P.O.	JOB NO.	CHG.	CASH	C.O.D.
3.00		55345	X		

QUANTITY	UNIT	DESCRIPTION	CODE	PRICE	EXTENSION
9.00	yd	CLASS AA AEA/WRA	7233		

WATER ADDED	ESTIMATED SLUMP	1	2	3	4	5	6	7	8	9	
	BEFORE WATER ADDED	1	2	3	4	5	6	7	8	9	CYLINDERS MADE
REQUESTED BY		25	50	75	100	125	150	180	205	230	
	AFTER WATER ADDED	1	2	3	4	5	6	7	8	9	CYLINDERS MADE

LEFT PLANT	ARRIVED JOB	START UNLOADING	FINISH UNLOADING	LEFT JOB	ARRIVED PLANT
845	908	911			

SUB TOTAL	
SALES TAX	
DELIVERY CHARGE	
HOLDING	
TICKET TOTAL	
JOB TOTAL	

ADDITIONAL TERMS OF SALE ON REVERSE SIDE OF TICKET

If buyer requests seller to make delivery across street curb, buyer agrees to be responsible for all damage done as a result thereof, including, but not limited to, damage to sidewalks, driveways, and grounds. Buyer agrees to indemnify, defend, and hold harmless seller in the event a claim is made against seller from damage arising from such actions.

Received above material in good condition.

Signature ______ Signature ______

CAUTION! SEE REVERSE OF TICKET FOR WARNING INFORMATION

CONTROL NO.. 39175

```
M-72   08:38     TRUCK #    499      TKT ID      55345    LD ID   57447
MATERIAL     REQUIRED    BATCHED   %MOISTURE  ACTUAL WAT
CEMENT         5499 lb     5480
467           15874 lb    15860    0.500% M     9.46 gl
SAND          13026 lb    13000    3.677% A    55.26 gl
WATER         187.0 gl    187.0               187.00 gl
AEA            54.0 oz     54.0
WRA           164.7 oz    164.0
NON-SIMULATED   NUM BATCHES: 2

SLUMP:  3.00 "
```

FORM NO. 6024

A SYMBOL OF QUALITY
A SYMBOL OF SERVICE

CUSTOMER

DOLESE

105 E. 7TH STREET • BOX 390 • ELK CITY, OK 73648-0390
PHONE (580) 225-1247

0588

SOLD TO MUSKOGEE BRIDGE CO INC	MUS350	TIME 08:54	DATE 04/26/2006	TICKET NO. 39179
DELIVER TO IMY-40-1(074)025.	DUE ON JOB	TRAVEL / SECTION	ORDER NO. 57448	QUANTITY ORDERED 40.00
DIRECTIONS I-40 AT 1ST SAYRE EXIT	PLANT M-72 / TRUCK 643	DRIVER SPRADLING		QUANTITY SHIPPED 40.00
	3.00	CONTRACT OR P.O.	JOB NO. 55347	CHG. X / CASH / C.O.D.

QUANTITY	UNIT	DESCRIPTION	CODE	PRICE	EXTENSION
10.00	yd	CLASS AA AEA/WRA	7233		

WATER ADDED: 10
REQUESTED BY: SAME

ESTIMATED SLUMP

BEFORE WATER ADDED	1	2	3	4	5	6	7	8	9
	25	50	75	100	125	150	180	205	230
AFTER WATER ADDED	1	2	3	4	5	6	7	8	9

CYLINDERS MADE: Ø
CYLINDERS MADE:

LEFT PLANT	ARRIVED JOB	START UNLOADING	FINISH UNLOADING	LEFT JOB	ARRIVED PLANT
902	921	1010	1050		

SUB TOTAL
SALES TAX
DELIVERY CHARGE
HOLDING
TICKET TOTAL
JOB TOTAL

ADDITIONAL TERMS OF SALE ON REVERSE SIDE OF TICKET

If buyer requests seller to make delivery across street curb, buyer agrees to be responsible for all damage done as a result thereof, including, but not limited to, damage to sidewalks, driveways, and grounds. Buyer agrees to indemnify, defend, and hold harmless seller in the event a claim is made against seller from damage arising from such actions.

Received above material in good condition.

Signature ____________ Signature Brooke Fr

CAUTION! SEE REVERSE OF TICKET FOR WARNING INFORMATION

CONTROL NO. 39177

M-72 08:54 TRUCK # 643 TKT ID 55347 LD ID 57448

MATERIAL	REQUIRED	BATCHED	%MOISTURE	ACTUAL WAT
CEMENT	6110 lb	6085		
867	17639 lb	17600	0.500% M	10.49 gl
SAND	14481 lb	14480	3.781% A	62.41 gl
WATER	207.1 gl	207.0		207.00 gl
AEA	60.0 oz	60.0		
WRA	183.0 oz	184.0		

NON-SIMULATED NUM BATCHES: 2

SLUMP: 3.00 "

FORM NO. 6024

A SYMBOL OF QUALITY
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DOLESE

105 E. 7TH STREET • BOX 390 • ELK CITY, OK 73648-0390
PHONE (580) 225-1247

0588

SOLD TO MUSKOGEE BRIDGE CO INC	MUS350	TIME 11:49		DATE 04/26/2006	TICKET NO. 39186
DELIVER TO IMY-40-1(074)025.	DUE ON JOB	TRAVEL	SECTION	ORDER NO. 57459	QUANTITY ORDERED 105.00
DIRECTIONS I-40 AT 1ST SAYRE EXIT	PLANT M-72	TRUCK 521	DRIVER J CHARTNEY		QUANTITY SHIPPED 57.00
	3.00	CONTRACT OR P.O.		JOB NO. 55357	CHG. X / CASH / C.O.D.

QUANTITY	UNIT	DESCRIPTION	CODE	PRICE	EXTENSION
9.00	yd	CONTRACTOR MIX NO GUARANTEE	8965		
	119 oz	Tetraguard			

WATER ADDED	ESTIMATED SLUMP BEFORE WATER ADDED	1	2	3	4	5	6	7	8	9	CYLINDERS MADE
		25	50	75	100	125	150	180	205	230	
REQUESTED BY	AFTER WATER ADDED	1	2	3	4	5	6	7	8	9	CYLINDERS MADE

LEFT PLANT	ARRIVED JOB	START UNLOADING	FINISH UNLOADING	LEFT JOB	ARRIVED PLANT
12:03	12:23				

SUB TOTAL

SALES TAX

DELIVERY CHARGE

HOLDING

TICKET TOTAL

JOB TOTAL

ADDITIONAL TERMS OF SALE ON REVERSE SIDE OF TICKET

If buyer requests seller to make delivery across street curb, buyer agrees to be responsible for all damage done as a result thereof, including, but not limited to, damage to sidewalks, driveways, and grounds. Buyer agrees to indemnify, defend, and hold harmless seller in the event a claim is made against seller from damage arising from such actions.

Received above material in good condition.

Signature ______ Signature ______

CAUTION! SEE REVERSE OF TICKET FOR WARNING INFORMATION

CONTROL NO.. 39186

M-72 11:49 TRUCK # 521 TKT ID 55357 LD ID 57459

MATERIAL	REQUIRED	BATCHED	%MOISTURE	ACTUAL WAT
CEMENT	5166 lb	5140		
WATER	157.9 gl	158.0		158.00 gl
#57	11623 lb	11680	0.500% M	6.96 gl
#8	3121 lb	3120	0.500% M	1.86 gl
SAND	14085 lb	14066	3.903% A	64.54 gl
AEA	~~34.0 oz~~	~~[illegible]~~		
MRWRA	715.5 oz	714.0		

NON-SIMULATED NUM BATCHES: 2

FORM NO. 6024

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CUSTOMER

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MAY 2 - 2006

0588

SOLD TO		TIME	DATE	TICKET NO.
MUSKOGEE BRIDGE CO INC	MUS350	12:10	04/26/2006	39187

DELIVER TO	DUE ON JOB	TRAVEL	SECTION	ORDER NO.	QUANTITY ORDERED
IMY-40-1(074)025.				57461	105.00

DIRECTIONS	PLANT	TRUCK	DRIVER	QUANTITY SHIPPED
I-40 AT 1ST SAYRE EXIT	M-72	669	S. POST	67.50

	CONTRACT OR P.O.	JOB NO.	CHG.	CASH	C.O.D.
3.00		55359	X		

QUANTITY	UNIT	DESCRIPTION	CODE	PRICE	EXTENSION
10.50	yd	CONTRACTOR MIX NO GUARANTEE	8965		
	1390z	Tetraguard			
		Too Dry to Pump After 3yds			

WATER ADDED	ESTIMATED SLUMP	BEFORE WATER ADDED	1	2	3	4	5	6	7	8	9	CYLINDERS MADE
REQUESTED BY			25	50	75	100	125	150	180	205	230	
		AFTER WATER ADDED	1	2	3	4	5	6	7	8	9	CYLINDERS MADE

LEFT PLANT	ARRIVED JOB	START UNLOADING	FINISH UNLOADING	LEFT JOB	ARRIVED PLANT
12:21	12:50	12:54			

SUB TOTAL	
SALES TAX	
DELIVERY CHARGE	
HOLDING	
TICKET TOTAL	
JOB TOTAL	

ADDITIONAL TERMS OF SALE ON REVERSE SIDE OF TICKET

If buyer requests seller to make delivery across street curb, buyer agrees to be responsible for all damage done as a result thereof, including, but not limited to, damage to sidewalks, driveways, and grounds. Buyer agrees to indemnify, defend, and hold harmless seller in the event a claim is made against seller from damage arising from such actions.

Received above material in good condition.

Signature ____________ Signature ____________

CAUTION! SEE REVERSE OF TICKET FOR WARNING INFORMATION

CONTROL NO.. 39187

M-72 12:10 TRUCK # 669 TKT ID 55359 LD ID 57461

MATERIAL	REQUIRED	BATCHED	%MOISTURE	ACTUAL WAT
CEMENT	6027 lb	6005		
WATER	157.7 gl	158.0		158.00 gl
#57	13560 lb	13540	0.500% M	8.07 gl
#8	3641 lb	3640	0.500% M	2.17 gl
SAND	16636 lb	16600	5.277% A	99.71 gl
AEA	# 126.0 oz	126.0		
MRWRA	# 0.0 oz	0.0		

NON-SIMULATED NUM BATCHES: 2

ODOT 4½ Slump
5.2% @ Truck

Tap-ODot 3¾
5.2 Air on Deck

FORM NO. 8024

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CUSTOMER

DOLESE

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0588

SOLD TO: MUSKOGEE BRIDGE CO INC — MUS350

TIME	DATE	TICKET NO.
13:17	04/26/2006	39191

DELIVER TO: IMY-40-1(074)025.

DUE ON JOB	TRAVEL	SECTION	ORDER NO.	QUANTITY ORDERED
			57462	105.00

DIRECTIONS: I-40 AT 1ST SAYRE EXIT

PLANT	TRUCK	DRIVER	QUANTITY SHIPPED
M-72	454	DOUG	76.50

	CONTRACT OR P.O.	JOB NO.	CHG.	CASH	C.O.D.
3.00		55362	X		

QUANTITY	UNIT	DESCRIPTION	CODE	PRICE	EXTENSION
9.00	yd	CONTRACTOR MIX NO GUARANTEE	8965		

WATER ADDED
REQUESTED BY

ESTIMATED SLUMP

BEFORE WATER ADDED	1	2	3	4	5	6	7	8	9	CYLINDERS MADE
	25	50	75	100	125	150	180	205	230	
AFTER WATER ADDED	1	2	3	4	5	6	7	8	9	CYLINDERS MADE

LEFT PLANT	ARRIVED JOB	START UNLOADING	FINISH UNLOADING	LEFT JOB	ARRIVED PLANT
118	140	145	159		

SUB TOTAL
SALES TAX
DELIVERY CHARGE
HOLDING
TICKET TOTAL
JOB TOTAL

ADDITIONAL TERMS OF SALE ON REVERSE SIDE OF TICKET

If buyer requests seller to make delivery across street curb, buyer agrees to be responsible for all damage done as a result thereof, including, but not limited to, damage to sidewalks, driveways, and grounds. Buyer agrees to indemnify, defend, and hold harmless seller in the event a claim is made against seller from damage arising from such actions.

Received above material in good condition.

Signature ____________ Signature ____________

CAUTION! SEE REVERSE OF TICKET FOR WARNING INFORMATION

CONTROL NO. 39191

M-72 13:17 TRUCK # 454 TKT ID 55362 LD ID 57462

MATERIAL	REQUIRED	BATCHED	%MOISTURE	ACTUAL WAT
CEMENT	5166 lb	5140		
WATER	150.5 gl	151.0		151.00 gl
457	11623 lb	11600	0.500% M	6.92 gl
8	3121 lb	3120	0.500% M	1.86 gl
SAND	14146 lb	14120	4.434% A	71.84 gl
AEA	# 162.0 oz	162.0		
MRWRA	# 900.0 oz	900.0		

NON-SIMULATED NUM BATCHES: 2

CUSTOMER

FORM NO. 6024

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0588

SOLD TO		TIME	DATE	TICKET NO.
MUSKOGEE BRIDGE CO INC	MUS350	13:41	04/26/2006	39192

DELIVER TO	DUE ON JOB	TRAVEL	SECTION	ORDER NO.	QUANTITY ORDERED
IMY-40-1(074)025.				57467	105.00

DIRECTIONS	PLANT	TRUCK	DRIVER	QUANTITY SHIPPED
I-40 AT 1ST SAYRE EXIT	M-72	626	R HOLFELDT	87.00

	CONTRACT OR P.O.	JOB NO.	CHG.	CASH	C.O.D.
3.00		55364	X		

QUANTITY	UNIT	DESCRIPTION	CODE	PRICE	EXTENSION
10.50	yd	CONTRACTOR MIX NO GUARANTEE	8965		

WATER ADDED	ESTIMATED SLUMP											
	BEFORE WATER ADDED	1	2	3	4	5	6	7	8	9	CYLINDERS MADE	
REQUESTED BY		25	50	75	100	125	150	180	205	230		SUB TOTAL
	AFTER WATER ADDED	1	2	3	4	5	6	7	8	9	CYLINDERS MADE	

LEFT PLANT	ARRIVED JOB	START UNLOADING	FINISH UNLOADING	LEFT JOB	ARRIVED PLANT	SALES TAX
13:46	14:04	14:15	1421			

ADDITIONAL TERMS OF SALE ON REVERSE SIDE OF TICKET

If buyer requests seller to make delivery across street curb, buyer agrees to be responsible for all damage done as a result thereof, including, but not limited to, damage to sidewalks, driveways, and grounds. Buyer agrees to indemnify, defend, and hold harmless seller in the event a claim is made against seller from damage arising from such actions.

Received above material in good condition.

Signature ______ Signature ______

DELIVERY CHARGE | HOLDING | TICKET TOTAL | JOB TOTAL

CAUTION! SEE REVERSE OF TICKET FOR WARNING INFORMATION

CONTROL NO. 39192

M-72 13:41 TRUCK # 626 TKT ID 55364 LD ID 57467

MATERIAL	REQUIRED	BATCHED	%MOISTURE	ACTUAL WAT
CEMENT	6027 lb	6005		
WATER	175.5 gl	175.0		175.00 gl
#57	13560 lb	13540	0.500% M	8.07 gl
8B	3641 lb	3640	0.500% M	2.17 gl
SAND	16505 lb	16500	4.443% A	84.11 gl
AEA	# 189.0 oz	189.0		
NRWRA	# 525.0 oz	526.0 + 524		

NON-SIMULATED NUM BATCHES: 2

OPT 8% AIR

FORM NO. 6024

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0588

SOLD TO		TIME	DATE	TICKET NO.
MUSKOGEE BRIDGE CO INC	MUS350	14:10	04/26/2006	39194

DELIVER TO	DUE ON JOB	TRAVEL	SECTION	ORDER NO.	QUANTITY ORDERED
IMY-40-1(074)025.				57468	105.00

DIRECTIONS	PLANT	TRUCK	DRIVER	QUANTITY SHIPPED
I-40 AT 1ST SAYRE EXIT	M-72	670	R. WADDLE	97.50

	CONTRACT OR P.O.	JOB NO.	CHG.	CASH	C.O.D.
3.00		55365	X		

QUANTITY	UNIT	DESCRIPTION	CODE	PRICE	EXTENSION
10.50	yd	CONTRACTOR MIX NO GUARANTEE	8965		

WATER ADDED	ESTIMATED SLUMP											
0	BEFORE WATER ADDED	1	2	3	4	5	6	7	8	9	CYLINDERS MADE	0
		25	50	75	100	125	150	180	205	230		
REQUESTED BY	AFTER WATER ADDED	1	2	3	4	5	6	7	8	9	CYLINDERS MADE	

LEFT PLANT	ARRIVED JOB	START UNLOADING	FINISH UNLOADING	LEFT JOB	ARRIVED PLANT
2:14	2:42	2:51	2:56		

SUB TOTAL	
SALES TAX	
DELIVERY CHARGE	
HOLDING	
TICKET TOTAL	
JOB TOTAL	

ADDITIONAL TERMS OF SALE ON REVERSE SIDE OF TICKET

If buyer requests seller to make delivery across street curb, buyer agrees to be responsible for all damage done as a result thereof, including, but not limited to, damage to sidewalks, driveways, and grounds. Buyer agrees to indemnify, defend, and hold harmless seller in the event a claim is made against seller from damage arising from such actions.

Received above material in good condition.

Signature ____________ Signature Pump

CAUTION! SEE REVERSE OF TICKET FOR WARNING INFORMATION

CONTROL NO. 39194

M-72 14:10 TRUCK # 670 TKT ID 55365 LD ID 57468

MATERIAL	REQUIRED	BATCHED	%MOISTURE	ACTUAL WAT
CEMENT	6027 lb	6005		
WATER	171.2 gl	171.0		171.00 gl
#57	13560 lb	13500	0.500% M	8.10 gl
#8	3641 lb	3640	0.500% M	2.17 gl
SAND	16540 lb	16500	4.665% A	88.13 gl
AEA	# 189.0 oz	189.0 263		
MRWRA	# 525.0 oz	524.0		

NON-SIMULATED NUM BATCHES: 2 +524

39194

FORM NO. 6024

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0588

SOLD TO		TIME	DATE	TICKET NO.
MUSKOGEE BRIDGE CO INC	MUS350	14:20	04/26/2006	39195

DELIVER TO	DUE ON JOB	TRAVEL	SECTION	ORDER NO.	QUANTITY ORDERED
IMY-40-1(074)025.				57469	105.00

DIRECTIONS	PLANT	TRUCK	DRIVER	QUANTITY SHIPPED
I-40 AT 1ST SAYRE EXIT	M-72	499	J BENNETT	106.50

	CONTRACT OR P.O.	JOB NO.	CHG.	CASH	C.O.D.
3.00		55367	X		

QUANTITY	UNIT	DESCRIPTION	CODE	PRICE	EXTENSION
9.00	yd	CONTRACTOR MIX NO GUARANTEE	8965		

WATER ADDED	ESTIMATED SLUMP		1	2	3	4	5	6	7	8	9	CYLINDERS MADE
		BEFORE WATER ADDED	25	50	75	100	125	150	180	205	230	
REQUESTED BY		AFTER WATER ADDED	1	2	3	4	5	6	7	8	9	CYLINDERS MADE

LEFT PLANT	ARRIVED JOB	START UNLOADING	FINISH UNLOADING	LEFT JOB	ARRIVED PLANT
237	245	256	303		

SUB TOTAL	
SALES TAX	
DELIVERY CHARGE	
HOLDING	
TICKET TOTAL	
JOB TOTAL	

ADDITIONAL TERMS OF SALE ON REVERSE SIDE OF TICKET

If buyer requests seller to make delivery across street curb, buyer agrees to be responsible for all damage done as a result thereof, including, but not limited to, damage to sidewalks, driveways, and grounds. Buyer agrees to indemnify, defend, and hold harmless seller in the event a claim is made against seller from damage arising from such actions.

Received above material in good condition.

Signature ______________ Signature ______________

CAUTION! SEE REVERSE OF TICKET FOR WARNING INFORMATION

CONTROL NO. 39195

M-72 14:20 TRUCK # 499 TKT ID 55367 LD ID 57469

MATERIAL	REQUIRED	BATCHED	%MOISTURE	ACTUAL WAT
CEMENT	5166 lb	5145		
WATER	144.6 gl	144.0		144.00 gl
857	11629 lb	11600	0.500% M	6.92 gl
#8	3121 lb	3120	0.500% M	1.86 gl
SAND	14195 lb	14180	4.801% A	77.84 gl
AEA	# 225.0 oz	225.0		
MRWRA	# 450.0 oz	450.0	+450	

NON-SIMULATED NUM BATCHES: 2

FORM NO. 6024

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CUSTOMER

DOLESE

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0588

SOLD TO		TIME	DATE	TICKET NO.
MUSKOGEE BRIDGE CO INC	MUS350	14:29	04/26/2006	39196

DELIVER TO	DUE ON JOB	TRAVEL	SECTION	ORDER NO.	QUANTITY ORDERED
IMY-40-1(074)025.				57471	105.00

DIRECTIONS	PLANT	TRUCK	DRIVER	QUANTITY SHIPPED
I-40 AT 1ST SAYRE EXIT	M-72	454	DOUG	115.50

	CONTRACT OR P.O.	JOB NO.	CHG.	CASH	C.O.D.
3.00		55368	X		

QUANTITY	UNIT	DESCRIPTION	CODE	PRICE	EXTENSION
9.00	yd	CONTRACTOR MIX NO GUARANTEE	8965		

	ESTIMATED SLUMP										
WATER ADDED	BEFORE WATER ADDED	1	2	3	4	5	6	7	8	9	CYLINDERS MADE
REQUESTED BY		25	50	75	100	125	150	180	205	230	
	AFTER WATER ADDED	1	2	3	4	5	6	7	8	9	CYLINDERS MADE

LEFT PLANT	ARRIVED JOB	START UNLOADING	FINISH UNLOADING	LEFT JOB	ARRIVED PLANT
235	250	306	312		

SUB TOTAL	
SALES TAX	
DELIVERY CHARGE	
HOLDING	
TICKET TOTAL	
JOB TOTAL	

ADDITIONAL TERMS OF SALE ON REVERSE SIDE OF TICKET

If buyer requests seller to make delivery across street curb, buyer agrees to be responsible for all damage done as a result thereof, including, but not limited to, damage to sidewalks, driveways, and grounds. Buyer agrees to indemnify, defend, and hold harmless seller in the event a claim is made against seller from damage arising from such actions.

Received above material in good condition.

Signature ______________ Signature ______________

CAUTION! SEE REVERSE OF TICKET FOR WARNING INFORMATION

CONTROL NO.. 39196

M-72 14:29 TRUCK # 454 TKT ID 55368 LD ID 57471

MATERIAL	REQUIRED	BATCHED	%MOISTURE	ACTUAL WAT
CEMENT	5166 lb	5145		
WATER	145.6 gl	145.0		145.00 gl
#57	11623 lb	11620	0.500% M	6.93 gl
#8	3121 lb	3120	0.500% M	1.86 gl
SAND	14187 lb	14160	4.741% A	76.80 gl
AEA	# 225.0 oz	225.0		
MRWRA	# 450.0 oz	450.0 +450		

NON-SIMULATED NUM BATCHES: 2

FORM NO.
6024

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0588

SOLD TO		TIME	DATE	TICKET NO.
MUSKOGEE BRIDGE CO INC	MUS350	14:43	04/26/2006	39198

DELIVER TO	DUE ON JOB	TRAVEL	SECTION	ORDER NO.	QUANTITY ORDERED
IMY-40-1(074)025.				57472	105.00

DIRECTIONS	PLANT	TRUCK	DRIVER	QUANTITY SHIPPED
I-40 AT 1ST SAYRE EXIT	M-72	669	S. POST	126.00

	CONTRACT OR P.O.	JOB NO.	CHG.	CASH	C.O.D.
3.00		55369	X		

QUANTITY	UNIT	DESCRIPTION	CODE	PRICE	EXTENSION
10.50	yd.	CONTRACTOR MIX NO GUARANTEE	8965		
	130				

WATER ADDED	ESTIMATED SLUMP											
3		BEFORE WATER ADDED	1	2	3	4	5	6	7	8	9	CYLINDERS MADE
REQUESTED BY			25	50	75	100	125	150	180	205	230	
		AFTER WATER ADDED	1	2	3	4	5	6	7	8	9	CYLINDERS MADE

LEFT PLANT	ARRIVED JOB	START UNLOADING	FINISH UNLOADING	LEFT JOB	ARRIVED PLANT
249	309	316	325		

SUB TOTAL	
SALES TAX	
DELIVERY CHARGE	
HOLDING	
TICKET TOTAL	
JOB TOTAL	

ADDITIONAL TERMS OF SALE ON REVERSE SIDE OF TICKET

If buyer requests seller to make delivery across street curb, buyer agrees to be responsible for all damage done as a result thereof, including, but not limited to, damage to sidewalks, driveways, and grounds. Buyer agrees to indemnify, defend, and hold harmless seller in the event a claim is made against seller from damage arising from such actions.

Received above material in good condition.

Signature ______________ Signature ______________

CAUTION! SEE REVERSE OF TICKET FOR WARNING INFORMATION

CONTROL NO. 39198

M-72 14:43 TRUCK # 669 TKT ID 55369 LD ID 57472

MATERIAL	REQUIRED	BATCHED	%MOISTURE	ACTUAL WAT
CEMENT	6027 lb	6000		
WATER	179.8 gl	180.0		180.00 gl
#57	13560 lb	13540	0.500% M	8.07 gl
#8	3641 lb	3640	0.500% M	2.17 gl
SAND	16469 lb	16440	4.215% A	79.68 gl
AEA	# 262.5 oz	263.0		
MRWRA	# 525.0 oz	524.0		

NON-SIMULATED NUM BATCHES: 2

FORM NO.
6024

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PHONE (580) 225-1247

0588

SOLD TO		TIME	DATE	TICKET NO.
MUSKOGEE BRIDGE CO INC	MUS350	15:00	04/26/2006	39199

DELIVER TO	DUE ON JOB	TRAVEL	SECTION	ORDER NO.	QUANTITY ORDERED
IMY-40-1(074)025.				57473	105.00

DIRECTIONS	PLANT	TRUCK	DRIVER	QUANTITY SHIPPED
I-40 AT 1ST SAYRE EXIT	M-72	626	R HOLFELDT	136.50

	CONTRACT OR P.O.	JOB NO.	CHG.	CASH	C.O.D.
3.00		55371	X		

QUANTITY	UNIT	DESCRIPTION	CODE	PRICE	EXTENSION
10.50	yd	CONTRACTOR MIX NO GUARANTEE	B965		

WATER ADDED	ESTIMATED SLUMP										
	BEFORE WATER ADDED	1	2	3	4	5	6	7	8	9	CYLINDERS MADE
REQUESTED BY		25	50	75	100	125	150	180	205	230	
	AFTER WATER ADDED	1	2	3	4	5	6	7	8	9	CYLINDERS MADE

LEFT PLANT	ARRIVED JOB	START UNLOADING	FINISH UNLOADING	LEFT JOB	ARRIVED PLANT
1504	1523	1533	1541		

SUB TOTAL	
SALES TAX	
DELIVERY CHARGE	
HOLDING	
TICKET TOTAL	
JOB TOTAL	

ADDITIONAL TERMS OF SALE ON REVERSE SIDE OF TICKET

If buyer requests seller to make delivery across street curb, buyer agrees to be responsible for all damage done as a result thereof, including, but not limited to, damage to sidewalks, driveways, and grounds. Buyer agrees to indemnify, defend, and hold harmless seller in the event a claim is made against seller from damage arising from such actions.

Received above material in good condition.

Signature ______ Signature [signature]

CAUTION! SEE REVERSE OF TICKET FOR WARNING INFORMATION

CONTROL NO. 39199

M-72 15:00 TRUCK # 626 TKT ID 55371 LD ID 57473

MATERIAL	REQUIRED	BATCHED	%MOISTURE	ACTUAL WAT
CEMENT	6027 lb	6000		
WATER	195.3 gl	195.0		195.00 gl
#57	13560 lb	13540	0.500% M	8.07 gl
#8	3641 lb	3640	0.500% M	2.17 gl
SAND	16339 lb	16320	3.395% A	64.21 gl
AEA	# 262.5 oz	262.0		
MRWRA	# 525.0 oz	526.0		

NON-SIMULATED NUM BATCHES: 2

FORM NO. 6024

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PHONE (580) 225-1247

0588

SOLD TO MUSKOGEE BRIDGE CO INC	MUS350	TIME 15:11	DATE 04/26/2006	TICKET NO. 39200
DELIVER TO IMY-40-1(074)025.	DUE ON JOB	TRAVEL / SECTION	ORDER NO. 57475	QUANTITY ORDERED 105.00
DIRECTIONS I-40 AT 1ST SAYRE EXIT	PLANT M-72 / TRUCK 643	DRIVER SPRADLING		QUANTITY SHIPPED 147.00
	3.00	CONTRACT OR P.O.	JOB NO. 55372	CHG. X / CASH / C.O.D.

QUANTITY	UNIT	DESCRIPTION	CODE	PRICE	EXTENSION
10.50	yd	CONTRACTOR MIX NO GUARANTEE	8965		
0		0	0		

WATER ADDED	ESTIMATED SLUMP		1	2	3	4	5	6	7	8	9	CYLINDERS MADE
		BEFORE WATER ADDED	25	50	75	100	125	150	180	205	230	0
REQUESTED BY		AFTER WATER ADDED	1	2	3	4	5	6	7	8	9	CYLINDERS MADE

LEFT PLANT	ARRIVED JOB	START UNLOADING	FINISH UNLOADING	LEFT JOB	ARRIVED PLANT
320	341	352	400		

SUB TOTAL	
SALES TAX	
DELIVERY CHARGE	
HOLDING	
TICKET TOTAL	
JOB TOTAL	

ADDITIONAL TERMS OF SALE ON REVERSE SIDE OF TICKET

If buyer requests seller to make delivery across street curb, buyer agrees to be responsible for all damage done as a result thereof, including, but not limited to, damage to sidewalks, driveways, and grounds. Buyer agrees to indemnify, defend, and hold harmless seller in the event a claim is made against seller from damage arising from such actions.

Received above material in good condition.

Pump

Signature ____________ Signature ____________

CAUTION! SEE REVERSE OF TICKET FOR WARNING INFORMATION

CONTROL NO.. 39200

M-72 15:11 TRUCK # 643 TKT ID 55372 LD ID 57475

MATERIAL	REQUIRED	BATCHED	%MOISTURE	ACTUAL WAT
CEMENT	6027 lb	6010		
WATER	189.9 gl	190.0		190.00 gl
#57	13560 lb	13540	0.500% M	8.07 gl
#8	3641 lb	3640	0.500% M	2.17 gl
SAND	16384 lb	16360	3.682% A	69.62 gl
AEA	# 262.5 oz	263.0		
MRWRA	# 525.0 oz	526.0		

NON-SIMULATED NUM BATCHES: 2

FORM NO. 6024

A SYMBOL OF QUALITY
A SYMBOL OF SERVICE

CUSTOMER

DOLESE

105 E. 7TH STREET • BOX 390 • ELK CITY, OK 73648-0390
PHONE (580) 225-1247

0588

SOLD TO: MUSKOGEE BRIDGE CO INC	MUS350	TIME: 15:32	DATE: 04/26/2006	TICKET NO.: 39201
DELIVER TO: IMY-40-1(074)025.	DUE ON JOB	TRAVEL	SECTION	ORDER NO.: 57477	QUANTITY ORDERED: 105.00
DIRECTIONS: I-40 AT 1ST SAYRE EXIT	PLANT: M-72	TRUCK: 670	DRIVER: R. WADDLE		QUANTITY SHIPPED: 157.50
	3.00	CONTRACT OR P.O.		JOB NO.: 55374	CHG.: X / CASH / C.O.D.

QUANTITY	UNIT	DESCRIPTION	CODE	PRICE	EXTENSION
10.50	yd	CONTRACTOR MIX NO GUARANTEE	8965		

WATER ADDED: 0	ESTIMATED SLUMP	BEFORE WATER ADDED	1	2	3	4	5	6	7	8	9	CYLINDERS MADE: 0
REQUESTED BY			25	50	75	100	125	150	180	205	230	
		AFTER WATER ADDED	1	2	3	4	5	6	7	8	9	CYLINDERS MADE

LEFT PLANT	ARRIVED JOB	START UNLOADING	FINISH UNLOADING	LEFT JOB	ARRIVED PLANT
3:38	3:57	4:06	4:33		

SUB TOTAL	
SALES TAX	
DELIVERY CHARGE	
HOLDING	
TICKET TOTAL	
JOB TOTAL	

ADDITIONAL TERMS OF SALE ON REVERSE SIDE OF TICKET

If buyer requests seller to make delivery across street curb, buyer agrees to be responsible for all damage done as a result thereof, including, but not limited to, damage to sidewalks, driveways, and grounds. Buyer agrees to indemnify, defend, and hold harmless seller in the event a claim is made against seller from damage arising from such actions.

Received above material in good condition.

Signature ______ Signature Pump Truck

CAUTION! SEE REVERSE OF TICKET FOR WARNING INFORMATION

CONTROL NO.: 39201

M-72 15:32 TRUCK # 670 TKT ID 55374 LD ID 57477

MATERIAL	REQUIRED	BATCHED	%MOISTURE	ACTUAL WAT
CEMENT	6027 lb	6000		
WATER	189.5 gl	189.0		189.00 gl
#57	13560 lb	13540	0.500% M	8.07 gl
#8	3641 lb	3660	0.500% M	2.10 gl
SAND	16384 lb	16360	3.680% A	69.58 gl
AEA	# 262.5 oz	263.0		
MRWRA	# 525.0 oz	522.0		

NON-SIMULATED NUM BATCHES: 2 +524

FORM NO. 6024

A SYMBOL OF QUALITY
A SYMBOL OF SERVICE

DOLESE

105 E. 7TH STREET • BOX 390 • ELK CITY, OK 73648-0390
PHONE (580) 225-1247

0588

SOLD TO		TIME	DATE	TICKET NO.
MUSKOGEE BRIDGE CO INC	MUS350	16:39	04/26/2006	39208

DELIVER TO	DUE ON JOB	TRAVEL	SECTION	ORDER NO.	QUANTITY ORDERED
IMY-40-1(074)025.				57485	105.00

DIRECTIONS	PLANT	TRUCK	DRIVER	QUANTITY SHIPPED
I-40 AT 1ST SAYRE EXIT	M-72	626	R HOLFELDT	168.00

	CONTRACT OR P.O.	JOB NO.	CHG.	CASH	C.O.D.
3.00		55382	X		

QUANTITY	UNIT	DESCRIPTION	CODE	PRICE	EXTENSION
10.50	yd	CONTRACTOR MIX NO GUARANTEE	8965		

WATER ADDED	ESTIMATED SLUMP										
	BEFORE WATER ADDED	1	2	3	4	5	6	7	8	9	CYLINDERS MADE
		25	50	75	100	125	150	180	205	230	
REQUESTED BY	AFTER WATER ADDED	1	2	3	4	5	6	7	8	9	CYLINDERS MADE

LEFT PLANT	ARRIVED JOB	START UNLOADING	FINISH UNLOADING	LEFT JOB	ARRIVED PLANT
16:43	17:02	17:12	17:43		

SUB TOTAL	
SALES TAX	
DELIVERY CHARGE	
HOLDING	
TICKET TOTAL	
JOB TOTAL	

ADDITIONAL TERMS OF SALE ON REVERSE SIDE OF TICKET

If buyer requests seller to make delivery across street curb, buyer agrees to be responsible for all damage done as a result thereof, including, but not limited to, damage to sidewalks, driveways, and grounds. Buyer agrees to indemnify, defend, and hold harmless seller in the event a claim is made against seller from damage arising from such actions.

Received above material in good condition.

Signature ______ Signature PUMP TRUCK

CAUTION! SEE REVERSE OF TICKET FOR WARNING INFORMATION

CONTROL NO. 39208

M-72 16:39 TRUCK # 626 TKT ID 55988 LD ID 57485

MATERIAL	REQUIRED	BATCHED	%MOISTURE	ACTUAL WAT
CEMENT	6027 lb	6015		
WATER	201.0 gl	200.0		200.00 gl
#57	13560 lb	13540	0.500% M	8.07 gl
#8	3641 lb	3640	0.500% M	2.17 gl
SAND	16291 lb	16260	3.092% A	58.44 gl
AEA	# 262.5 oz	263.0		
MRWRA	# 0.0 oz	0.0	520 + 1640	

NON-SIMULATED NUM BATCHES: 2

39208

Appendix J – Unit Conversions

Mixture Proportions and Batching
1 kg/m^3 = 1.686 lb/yd^3
1 kg = 2,205 lb
0.765 m^3 = 1 yd^3 = 27 ft^3

Admixtures
1 L/m^3 = 25.85 $fl.oz/yd^3$ = 1 gal/yd^3
1 m^3 = 1,000 L
3.785 L = 1 gal =128 fl.oz
1 lb = .0089 cwt = 0.4537 kg

Fresh Concrete Properties
25.4 mm = 1 in
$^oC = 5/9(^oF – 32)$
1 kg/m^3 = 0.06243 lb/ft^3

Mechanical Properties
1 MPa = 145 psi