THE EFFECTS OF VISUAL STABILITY INDEX (VSI) ON FRESH AND HARDENED PROPERTIES OF SELF CONSOLIDATING CONCRETE (SCC) UNDER ACCELERATED CURING CONDITION

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ABSTRACT

Self-consolidating concrete, also known as self-compacting concrete (SCC), is a highly flowable concrete that spreads into place and fills formwork without the need for mechanical vibration. SCC reduces the time and labor cost needed for concrete placement. This study is part of the proposed project by Tennessee Department of Transportation (TDOT) carried out by University of Tennessee at Chattanooga (UTC) to develop four new SCC mixtures (two Class P-SCC (precast) and two Class A-SCC (general use), and insure they meet the minimum strength and durability requirements for TDOT Clss P and Class A mixtures. The objectives of the study presented in this thesis are to analyze effects of visual stability index (VSI) on both fresh and hardened properties of Class P-SCC concrete under the accelerated curing using SURE CURE system. In addition, the relationship between VSI and fresh segregation of SCC is investigated. Finally, the results of this study are evaluated to recommend performance specifications for Class P-SCC for TDOT adoption of SCC standard operating procedures

DEDICATION

I dedicate my dissertation work to my family and many friends. A special feeling of gratitude to my loving mother, Nagwa whose words of encouragement and push for tenacity ring in my ears. My brothers Tarig and Ahmed have never left my side and are very special.

Finally I dedicate this dissertation to the soul of my father whose picture had never got out of my mind. Also to the soul of my friend Ali who died in a young age.

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INTRODUCTION

1.1 Background

Self-consolidating concrete (SCC) or self-compacting concrete, as it is sometimes known, arrived as a revolution in the field of concrete technology. The concept was proposed by Professor Hajime Okamura of Kochi University of Technology, Japan, in 1986 as a solution to the growing concrete durability concerns of the Japanese government. During his research, Okamura found that the main cause of the poor durability performances of Japanese concrete in structures was the inadequate consolidation of the concrete in the casting operations. By developing concrete that self-consolidates, he eliminated the main cause for the poor durability performance of their concrete. By 1988, the concept was developed and ready for the first real-scale tests(Vachon, 2002).

Generally, SCC is made with conventional concrete materials with the addition of chemical admixture such as viscosity-modifying admixture (VMAs) to enhance cohesion and control the tendency of segregation resulting from the highly flowable SCC (ACI, 2007; Elhassan, 2014). Also, the fine aggregate content in SCC is higher than that for conventional concrete in order to provide better lubrication for course aggregates to enhance workability of the mixture (Adekunle, 2012).

Here are some of the advantages of SCC compared to conventional concrete:

- Reduced amount of labor and equipment needed

- Better consolidation in congested areas
- Reduced noise
- Safer working environment
- More detailing flexibility
- Smooth surfaces
- Self-leveling
- Better hardened properties

1.2 Objectives of the Study

This Study is part of research project proposed and carried out by The University of Tennessee at Chattanooga (UTC) and funded by Tennessee Department of Transportation (TDOT) to develop four new SCC mixtures (two Class P-SCC and two Class A-SCC), and insure they meet the minimum strength and durability requirements for TDOT Class P and Class A mixtures.

The primary objectives of this study were as follows:

- Investigate the fresh properties of SCC in comparison to conventional concrete.
- Investigate the relationship between Visual Stability Index (VSI) and fresh-segregation of SCC.
- Investigate the effect on fresh properties of class F fly ash, and various gradations of coarse and fine aggregates.
- Investigate the effect of accelerated curing process on the hardened properties represented by compressive strength, tensile strength and Modulus of elasticity.

- Recommend the specification of fresh performance requirements for (Class P) SCC that TDOT should apply to establish SCC stability and flowability during the production of precast elements.
- Recommend the hardened requirements of Class P –SCC that TDOT should apply to establish strength and durability to be considered in the design of the precast elements.

1.3 Research Approach

The study was divided into six major activities which were:

1. Conducting a comprehensive literature review about the state of the art of SCC in United States and the rest of the world. The literature review described the current practices and types of materials used, beside all types of tests used.
2. Typical Class P materials such as Supplementary Cementitious Materials (SCMs), coarse aggregate, fine aggregates, cement, Class F fly ash, and some chemical admixtures were acquired from local TDOT suppliers. Also, in this activity, the test specimens molds and experimental accessories were prepared as well as necessary equipment calibration was conducted.
3. Development of candidate Class P-SCC mixtures. One Class P-SCC mixtures were developed, with 20% replacements of cement with Class F and the other mix without any replacement. These mixture proportions were developed based on the trial minimum requirement determined in activity one. Several conventional concrete mixtures were developed for the Class P to evaluate the performance of the SCC mixtures in comparison to conventional concrete. A total of 12 batches of each candidate mixture were developed

using different coarse aggregate gradations, natural and manufactured sand as described in Section 4.

4. The 12 batches of each candidate mixture were tested with a variety of fresh consistencies and aggregate blends. Each Conventional mixture underwent standard fresh property testing which includes: slump (ASTM C 143); Unit Weight and Gravimetric Air Content (ASTM C 138); Air Content by Pressure Method (ASTM C 231). In addition SCC mixtures were subjected to the same fresh test except slump, and underwent additional fresh tests which include: Slump Flow and Visual Stability Index (ASTM C 1611); Consolidating ability by J-Ring (ASTM C 1621); Static Segregation by Column Test (ASTM C 1610); and L-Box.
5. Casting of SCC specimens for the proposed hardened tests on the candidate mixtures after being cured under the accelerated curing process. Each Class P-SCC mixture will be tested at 18 hours, 28, and 56 days. Each mixture will undergo standard hardened property testing which includes: compressive strength, splitting tensile strength, modulus of elasticity, rapid chloride permeability, and hardened concrete segregation by ultrasonic pulse velocity.
6. In the final activity, the fresh and hard properties data were compiled, analyzed and the effects of Visual Stability Index (VSI) on fresh segregation of SCC and compressive strength was investigated.

1.4 Study Outline

This study consists of five chapters. The first chapter discusses the historical background of SCC, The advantages of using SCC. Also the chapter includes the objectives of the study, and research approach to perform the study.

The second chapter will summarize a literature review about all the aspects of SCC and focus on the activity of accelerated curing performed in the project. The mixture proportioning, fresh and hardened properties of SCC will be discussed. Also, a summary of the methods used to assess the fresh and hardened properties are addressed.

Chapter 3 documents the development of the 16 SCC mixtures and 8 conventional concrete mixtures. A detailed description of theses mixtures is discussed which includes, but are not limited to, the selection of aggregate gradation, cementation materials, chemical admixtures, and air entrained admixture. Also, the mixing procedure is documented, followed by descriptions of the fresh and hardened properties measured during this study.

The results of the fresh and hardened SCC tests are presented in Chapter 4. All conclusions and recommendations derived from the study beside discussions of the results are then summarized in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

As mentioned in the previous chapter, SCC is an advanced type of concrete that can flow through obstacles and fill formwork under its own weight without mechanical vibration. The application of SCC has major impacts on the way concrete is specified, produced, and placed. The use of SCC can result in increased productivity in construction, improved jobsite safety, and improved hardened properties. Although SCC can potentially decrease total project costs through minimization of labor, SCC can result in a higher per unit cost compared to conventional concrete due to increased Cementious materials, chemical admixtures, more strict specifications and the need for the advanced technical expertise. The proper selection of materials and mixture proportions is an important factor to ensure that the advantageous properties of SCC can be achieved economically. The effects of individual constituents and of changes in mixture proportions are often greater in SCC than in conventionally placed concrete (Koehler, 2007).

In this chapter the materials that used to make SCC and the tests to measure the performance of SCC are discussed. The tests are categorized into two main categories which are tests to measure fresh properties of SCC and tests to measure the hardened properties. Class-P concrete is concrete type that is subjected to accelerate curing, since that is the case accelerated curing concept will be discussed. A brief survey summary was mentioned at the end of the chapter about what are the current practices of SCC at other Department of Transportation inside the United States. The survey was conducted by the University of Tennessee at Chattanooga at the beginning of this project to evaluate the current practices performed by other states according to their specifications.

2.2 Materials Used in SCC

Materials used in SCC are the same materials used in conventional concrete. Although SCC can be made with a wide range of materials, the proper combination of the materials is crucial for optimizing SCC. Compared to conventional concrete, SCC is more sensitive to changes in material properties (Koehler, 2007). The following will describe the different types of materials that being used to produce SCC.

2.2.1 Cementitious Materials

Cementitious materials are the components that bind all of the other concrete components together. The combination of portland cement, supplementary cementitious materials and water is defined as cement paste. SCC mixtures that produce satisfactory results typically have between usually have 650 lb/yd^3 to 840 lb/yd^3 (385 kg/m3 to 500 kg/m3) Cementious materials content (Mata, 2004). SCC typically includes portland cement and supplementary cementitious materials like fly ash, silica fume, and any material that grinds to less than 0.125 mm (No.100 sieve) (ACI, 2007). SCC often has higher cementitious materials content than conventionally placed concrete in order to achieve adequate flowability and to reduce segregation. The potential negative consequences of high cementitious materials content include higher cost, higher heat of hydration, and increased susceptibility to creep and shrinkage. Fly ash is a byproduct from burning pulverized coal in electric power generating plants. During combustion, mineral impurities in the coal (clay, feldspar, quartz, and shale) fuse in suspension and float out of the combustion chamber with the exhaust gases. As the fused material rises, it cools and solidifies into spherical glassy particles called fly ash. Fly ash is used as a supplementary cementitious material (SCM) in the production of portland cement concrete. A supplementary cementitious material, when used in conjunction with portland cement, contributes to the properties of the hardened concrete through hydraulic or pozzolanic activity, or both (Thomas, 2007).

Fly ash is a fine powder made up of hollow ferroaluminosilicate particles enriched with Ca, K and Na, and is collected from the flue gas during coal combustion by mechanical filters or electrostatic precipitators. Typical fly ash particle sizes are within 0.1-1.0 µm, and electron microscopy has revealed particles with rough surfaces covered with smaller adhering spherical particles (Sajwan, 2006). Two types of fly ash are commonly used in concrete: Class C and Class F. Class C are often high-calcium fly ashes with carbon content less than 2%; while, Class F are generally low-calcium fly ashes with carbon contents less than 5% but sometimes as high as 10%.

Silica fume, Class F fly ash, and ground granulated blast furnace slag (GGBFS) reduce permeability and improve the chemical durability of moist cured concrete. Silica fume and Class F fly ash are primarily pozzolanic materials, while GGBFS is primarily a cementitious material. For precast operations, silica fume has been the most commonly used, but the use of Class F fly ash and slag has increased in recent year (Mata, 2004).

2.2.2 Aggregate (EFNARC, 2002)

SCC typically contains both types of aggregate fine and coarse aggregate. For Fine aggregate or sand, all normal concreting sands are suitable for SCC. Both manufactured (crushed) and natural (rounded) sands can be used. The amount of fines less than No.100 sieve (0.125 mm) is to be considered as powder and is very important for the rheology of the SCC. A minimum amount of fines must be achieved to avoid segregation. For Coarse Aggregates, all types of aggregates are suitable. The normal maximum size is generally 16-20 mm; however particle sizes up to 40 mm or more have been used in SCC. Consistency of grading is of vital importance. Regarding the characteristics of different types of aggregate, crushed aggregates tend to improve the strength because of the interlocking of the angular particles, while rounded aggregates improve the flow because of lower internal friction. Gap graded aggregates are frequently better than those continuously graded, which might experience greater internal friction and give reduced flow.

Aggregate angularity affects mortar and concrete properties primarily by changing water demand. Lower angularity fine aggregates are typically desired, if available. Manufactured sands tend to be more angular than natural sands due to the crushing operations needed to produce the sand and to the lack of abrading occurring with natural sands. The crushing process also tends to produce a considerable quantity of fines that must be wasted unless permitted to remain in the manufactured sand. Since the fines are primarily stone dust rather than clay or other contaminants, a higher percentage is allowed in manufactured sand specifications. The higher fines content will also increase water demand, all else being equal. Angularity of fine aggregate is usually quantified as the void content using the method proposed by the National Aggregates Association and standardized as ASTM C 1252. Particle shape will clearly affect the void content, but individual particle shape analysis has been conducted on coarse aggregate constituents. A similar analytical tool for fine aggregate would be useful (Dilek, 2004).

2.2.3 Admixtures

Admixtures were critical components in the development of SCC. There are many types of admixtures that are used in the production of SCC to enhance fresh properties as well as affect the hardened properties. The most commonly used admixtures in SCC mixtures are High Range Water Reducer Admixtures (HRWRA), Air Entraining Admixtures (AEA) and Viscosity Modifying Admixtures (VMAs).

HRWRA can be used to maintain a relatively low water cement ratio (w/cm) while increasing fluidity. The deformability of the paste is increased by reducing the viscosity. HRWRA can provide a highly flowable concrete without a significant reduction in cohesiveness and improve the resistance to segregation (ACI, 2007; Khayat, Assaad, & Daczko, 2004).

In some cases the creation of voids and microscopic bubbles is necessary inside the concrete to provide a space for expansion of water when it freezes. AEA are used to create these voids inside the concrete which is a typical behavior in the cold areas.

Viscosity-modifying admixtures, also known as anti-washout admixtures when used in higher dosages, generally increase some or all of the following properties in concrete mixtures: yield stress, plastic viscosity, thixotropy, and degree of shear thinning. They can be used for SCC applications to improve segregation resistance, increase cohesion, reduce bleeding, allow the use of a wider range of materials such as gap-graded aggregates and manufactured sands, and mitigate the effects of variations in materials and proportions. They may be used as an alternative to increasing the powder content or reducing the water content of a concrete mixture (Koehler, 2007).

2.2.4 Mixing Water

Normal potable water should be used during mixing the SCC concrete. Water-to-cementitious-material ratio (w/cm) and the strength of concrete are inversely related. A low w/cm should be applied to obtain high strength especially in the precast concrete industry because high early-age strengths are desirable. A suitable amount of water should be added to the mix to obtain higher level of workability and stability; Therefore, HRWRA are used to increase the workability of SCC mixtures (Elhassan, 2014).

2.3 Fresh Properties Tests

A number of fresh properties that includes filing ability, passing ability and fresh segregation of aggregates can be tested using the following tests procedures:

2.3.1 Slump Flow Test ASTM C 1611 (ASTM, 2005)

The slump flow test is a test to measure the Flowability of SCC. It is similar to the conventional slump flow, however the diameter is measured instead of measuring the slump height. Usually the diameter range is from 18 inch to 32 inch. See Figure 2.1 for an example of slump flow test.

Figure 2.1 Slump Flow Test

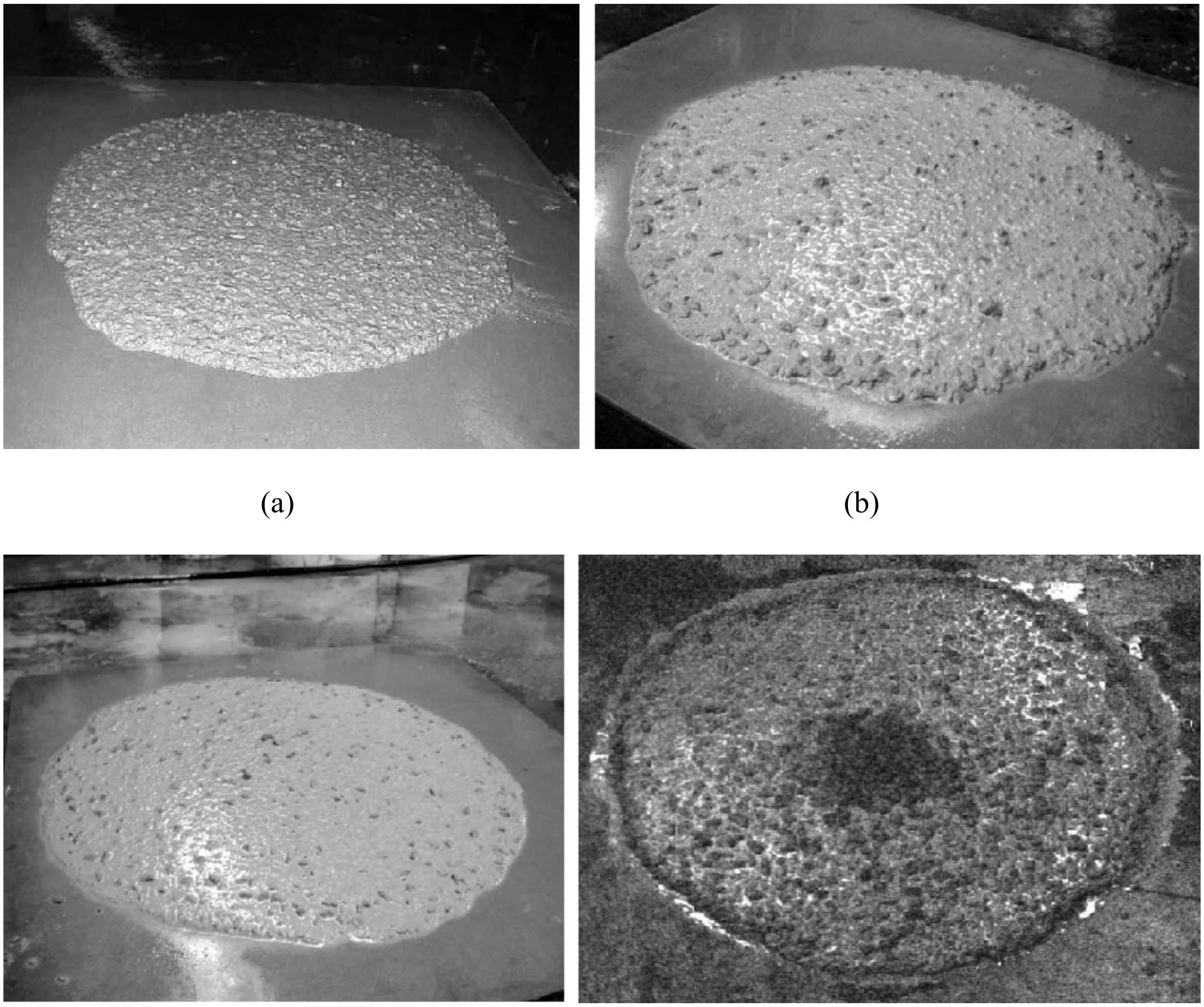
2.3.2 J-ring Test (ASTM C 1621)

The J-ring is a test method to measure the passing ability of SCC. J-ring has the same procedure of slump flow test, the only difference is that a steel reinforced with bars ring is placed around the standard slump cone. A sample of fresh SCC is placed into the cone. The mold is raised, the SCC passes through J-ring, and the J-ring patty diameter is measured (ASTM, 2009). The higher the J-ring slump flow value, the greater relative ability the SCC has to fill a steel reinforced form or mold under its own weight (ACI, 2007). The method is just a simulation to what can happened in steel reinforcement form work. See Figure 2.2 for an example of J-ring test.

Figure 2.2 J-ring Test

2.3.3 Visual Stability Index (VSI) (ASTM C 1611)

The Visual Stability Index (VSI) is a method for determining the segregation stability of the mixture, and to evaluate the relative stability of batches of the same SCC mixture. The VSI is determined through visually rating apparent stability of the slump flow patty based on specific visual properties of the spread. The SCC mixture is considered stable and suitable for the intended use when the VSI rating is 0 or 1, and a VSI rating of 2 or 3 gives an indication of segregation potential (ACI, 2007). Figure 2.3 shows the different values of VSI assigned, Plate (a) VSI = 0 – concrete mass is homogeneous and no Evidence of bleeding. Plate (b) VSI = 1 – Concrete Shows Slight Bleeding Observed as a Sheen on the Surface. Plate (c) VSI = 2 – Evidence of a Mortar Halo and Water Sheen. Plate (d) VSI = 3 – Concentration of Coarse Aggregate at Center of Concrete Mass and Presence of a Mortar Halo (ASTM, 2005).



(a) (b)

(c) (d)

Figure 2.3 Visual Stability Index

2.3.4 T50 (ASTM C 1611)

The T50 value is test to measure the relative viscosity of SCC. The test measures the time for the slump flow paddy to reach a diameter of 20 in (50 cm). A longer time indicate a greater relative viscosity mixture, and vice versa (ACI, 2007). ACI Committee 237 reports that a SCC mixture can be characterized as a lower viscosity mixture when the T50 time is less than or equal to 2 seconds, and as a higher viscosity mixture if greater than 5 seconds. The T50 test and slump flow test are typically performed simultaneously.

2.3.5 L-Box Test

L-box is a test method to measure the passing ability of SCC that is subjected to reinforcement blockage. The container consists of an ‘’L’’ shape rectangular box, with a vertical and horizontal section, separated by a sliding door, in front of which vertical lengths of reinforcement bars are fitted. The SCC is poured in the vertical section, and the door is lifted to let the concrete flow into the horizontal section. When the flow stops, the heights of the concrete are measured at the end of the horizontal section and in the vertical section. The L-Box result is the ratio of the height of concrete in the horizontal section to remaining in the vertical section. ACI Committee 237 specified the minimum ratio of the heights to be 0.8, and the nearer this ratio to 1.0 is the better flow potential of the SCC mixture. An example of L-Box testing apparatus is show in Figure 2.4 (ACI, 2007; Elhassan, 2014).

Figure 2.4 L-Box Testing Apparatus

2.3.6 Column Segregation Test (ASTM C 1610)

Column segregation is a test method used to measure the fresh segregation on SCC. The test is filing 26 inch column that has three sections with fresh SCC and let rest for 15 minutes. After that each section s removed, and the concrete in the top and the bottom section are washed over No. 4 sieve, and retained aggregate is weighed. The less difference in weight between the top and bottom the less segregation the concrete is. Figure 2.5 is an example of column segregation equipment ACI, 2007).

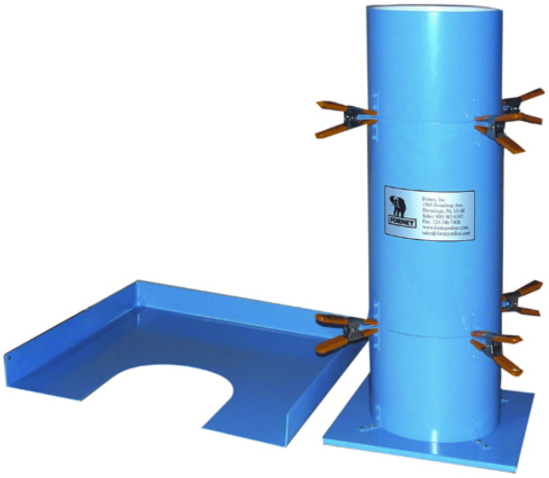


Figure 2.5 Column Segregation Apparatus

2.4 Hardened Properties Tests

The hardened properties and behavior of SCC are similar to conventional concrete. The tests that are used to assess the performance of hardened properties usually are Compressive Strength (ASTM C 39), Static Modulus of Elasticity (ASTM C 469) and Splitting Tensile Strength (ASTM C 496). SCC may have a lower modulus of elasticity due to lower coarse aggregate content, which may affect deformation characteristics of pre-stressed concrete members. Additionally, creep and shrinkage are expected to be higher for SCC due to its high paste content, affecting pre-stress loss and long term deflection, although this may be offset in part due to relatively low w/cm of SCC commonly used in precast operations (Mata, 2004).

Other tests may be used to assess the hardened segregation of the concrete like Ultra-Sonic Pulse Velocity, which is testing a hardened column using the ultra-sonic pulse velocity equipment. The test is measuring the velocity of an induced sound wave on the top and the bottom of the column. Differences in pulse velocity indicates greater segregation occurred in the concrete.

2.5 Accelerated Curing of SCC

Accelerated curing is a way to achieve a high early age strength. This practice is most common in the precast industry, where there is a need for concrete elements to be casted and transported as quickly as possible to the site. The idea behind the accelerated curing is by increasing the concrete temperature, the rate of hydration increases and a larger portion of the later-age properties of the concrete can be attained during the short curing period compared with standard temperature curing. Different curing methods are being used to accelerate the curing process. Warm water, boiling water, and steam curing are all curing methods that have been used for a long time to cure concrete. With these methods, concrete is subjected to boiling water or steam after 6 hours of being casted for about 12 hours to achieve high early age strength.

A new technique for accelerated curing was developed by a company called Products Engineering based Colorado. The technique is based on generating the heat needed for curing the concrete using the electricity, the system developed based on that idea known as SURE CURE system. The company developed both on site system to cure concrete in production and cylinders which is being used for research. The SURE CURE Curing Control System is a computer-based concrete curing controller which allows to enter the desired temperature profile for your concrete cylinders. Figure 2.6 below describes how the approach and connectivity of the different parts of the curing elements.

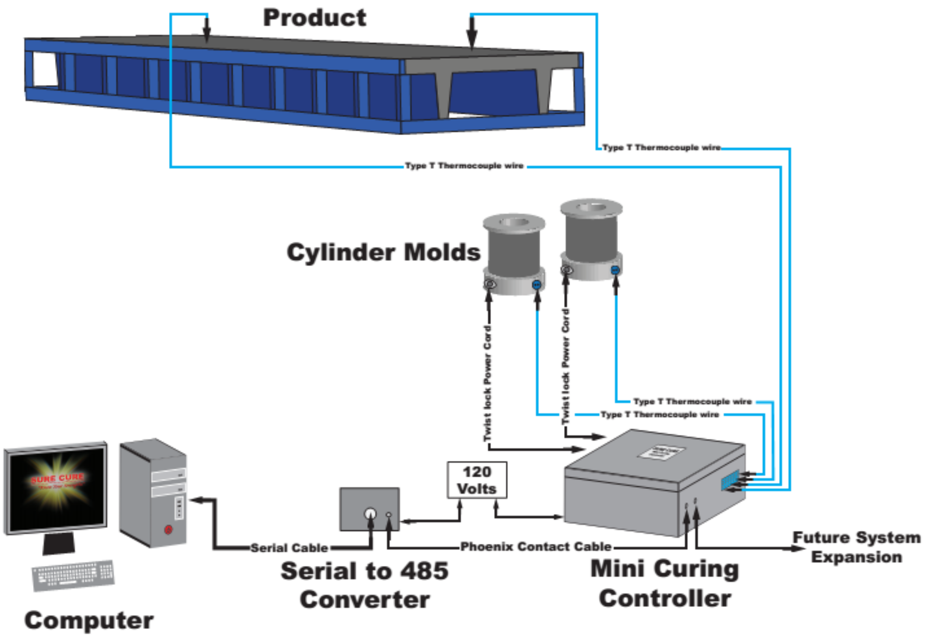


Figure 2.6 SURE CURE System

2.6 Survey of The State SCC practices

A Survey was performed by The University of Tennessee at Chattanooga to gather specifications related to SCC use in other states. The results of the survey showed that among 24 states Oregon and Michigan do not allow SCC on their projects. South Carolina responded that there was no industry demand for SCC. Also the survey results showed that 12 states allow for SCC in precast application through specification or special provision. Seven states allow SCC for general use through specification or special provision. SCC is allowed in drilled shaft foundations in 4 states through special provision or specification. Three states allow SCC for other uses (Elhassan, 2014).

CHAPTER 3

EXPERIMENTAL PROCEDURE

3.1 Introduction

The purpose of the experimental procedure is to develop a plan that will facilitate the analysis of the effect of Visual Stability Index on fresh and hardened properties of SCC under accelerated curing condition. In this chapter mixture proportions, materials used and testing procedures will be discussed. Mixing procedures, preparation and curing of the specimens and the test methodologies are also reviewed.

This study is part of a project funded by Tennessee Department of Transportation (TDOT) to develop two types of mixtures on SCC (Class-A for general use and Class-P for precast purposes). Only Class-P SCC will considered in this study.

3.2 Mix Design Proportions

Mixture proportions were developed based on the information obtained from the DOT survey conducted by The University of Tennessee at Chattanooga in cooperation with the TDOT materials and Tests division. Two sets of mixtures were developed to assess the effect of VSI on both hardened and fresh properties of Class-P SCC. Each set consist of four Trial mixtures groups. Portland cement was used only as a cementitious materials on the first batch, whereas portland cement plus Class-F fly ash is used in the second set. Fly ash was designed to be 20% of the cementitious materials in the second batch. TDOT set a maximum of 658 lbs. of cementitious materials to be used in their mixtures but since the this value did not achieve the strength requirement of 4000 psi in 18 hours, the cement content was increased by 20 lbs.

The groups in each set were divided on the basis (ASTM C 33) coarse aggregate sizes and fine aggregates used. The first group in each set was using #67 stone and natural sand, while the second group was designed to have #67 stone and manufactured sand. The third and fourth group had the same fine aggregates which was natural sand, however the difference was #7 stone used as a coarse aggregate in the third group, while #89 stone was used in the fourth group. A total of 12 mixtures were in each set result in 24 mixtures to be tested. Each group consist of three mixtures, two of them were SCC mixtures with varying VSI value; while the third mix is a conventional concrete mix used as a control mix.

SCC mixtures were designed with 50% fine aggregates of the total volume to provide the necessary filling, passing, and flowability characteristics, and a 44% fine aggregate was used for conventional concrete mixtures. Typically, all the mixtures were designed with 0.45 water cementitious materials ratio. In addition, the TDOT Class P mixtures were developed to have no air entertained in the concrete, since high early age strength is required. Only 2% of entrapped air was allowed in the mixtures. Mixture proportions are provided in Tables 3.1 and 3.2. The aggregate weights are provided for the saturated-surface dry condition. HRWRA values in the Table were estimated in the design, but the actual values were obtained during the mix process to produce the required VSI.

Table 0.1 TDOT Class A Mixtures with Portland Cement

Mixture No	1	2	3	4	5	6	7	8	9	10	11	12
VSI	1	2	Conv.	1	2	Conv.	1	2	Conv.	1	2	Conv.
Cement	678	678	678	678	678	678	678	678	678	678	678	678
Class F-Ash	0	0	0	0	0	0	0	0	0	0	0	0
# 67 stone	1551	1551	1735	1550	1550	1735	0	0	0	0	0	0
# 7 stone	0	0	0	0	0	0	1551	1551	1735	0	0	0
# 89 stone	0	0	0	0	0	0	0	0	0	1551	1551	1735
Natural sand	1470	1470	1295	0	0	0	1470	1470	1295	1470	1470	1295
Manufactured sand	0	0	0	1550	1550	1364	0	0	0	0	0	0
Design Air	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
Water	304	304	304	304	304	304	304	304	304	304	304	304
AEA (oz. /yd.)	0	0	0	0	0	0	0	0	0	0	0	0
H/MRWR (oz./cwt)	7	9	4	7	9	4	7	9	4	7	9	4
w/cm ratio	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Sand ratio by volume	0.5	0.5	0.44	0.5	0.5	0.44	0.5	0.5	0.440	0.5	0.5	0.44

All weights in lbs. /yd^3.
HRWR dosages are design values, the actual values are shown in Chapter 4.
Admixture demands are dependent on aggregates.
Con.: Conventional concrete.

Table 0.2 TDOT Class A Mixtures with 20% Cement Replacement of Class F fly Ash

Mixture No	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
VSI	1	2	Conv.	1	2	Conv.	1	2	Conv.	1	2	Conv.
Cement	543	543	543	547	547	547	543	543	543	543	543	543
F-Ash	135	135	135	131	131	131	135	135	135	135	135	135
# 67 stone	1536	1536	1720	1536	1536	1720	0	0	0	0	0	0
# 7 stone	0	0	0	0	0	0	1536	1536	1720	0	0	0
# 89 stone	0	0	0	0	0	0	0	0	0	1536	1536	1720
Natural sand	1455	1455	1280	0	0	0	1455	1455	1280	1455	1455	1280
Manufactured sand	0	0	0	1535	1535	1350	0	0	0	0	0	0
Design Air	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
Water	304	304	304	304	304	304	304	304	304	304	304	304
AEA (oz. /yd.)	0	0	0	0	0	0	0	0	0	0	0	0
H/M-RWR (oz./cwt)	7	9	4	7	9	4	7	9	4	7	9	4
w/cm ratio	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Sand ratio by volume	0.5	0.5	0.44	0.5	0.5	0.44	0.5	0.5	0.440	0.5	0.5	0.44

All Weights in lbs. /yd^3.

HRWR dosages are design values, the actual values are shown in Chapter 4.

Admixture demands are dependent on aggregates.

Con.: Conventional concrete

3.3 Materials Used in the Experiment

3.3.1 Cementitious materials

Portland cement (ASTM C 150) Type I and Class F (ASTM C 618) fly ash were the only cementitious materials used in the project. All the cement that used in the project were acquired locally from Buzzi Unicem USA- Chattanooga. The stock was stored in the laboratory during the study period. The chemical composition of the cement is shown in Table 3.3. As mentioned earlier in this chapter, there were two sets of mixtures. The difference between the two sets was using the Class F Fly ash to replace 20 % of portland cement in the mixtures in the second set. All amount of Class F fly used was acquired locally from The SEFA Group Cumberland City, TN, and was kept in the laboratory during the study period. The chemical composition of Class F fly ash is shown in Table 3.4.

Table 0.3 The Chemical Composition of the Portland Cement.

Component	**Weight %**	**Component**	**Weight %**
SiO_2	19.8	C_3S	64.1
Al_2O_3	4.6	C_2S	8.3
Fe_2O_3	3.5	C_3A	6.2
CaO	63.3	C_4AF	10.7
MgO	3	$C_3S+4.75C_3A$	93.3
SO_3	2.7	CO_2	1.2
Total alkalis(Na_2O +0.658 K_2O	0.53	Limestone	3.1
Ignition Loss	1.7	$CACO_3$ in Limestone	89.2
Insoluble Residue	0.3	-	-

Table 0.4 The Chemical Composition of Class F fly Ash.

Component	Weight %	Component	Weight %
SiO_2	44.29	CaO	8.87
Al_2O_3	18.39	MgO	0.86
Fe_2O_3	19.23	SO_3	2.72
Sum of Constituents	81.9	Loss on Ignition	1.65
Available Alkalis as Na_2O	0.84	Moisture Content	0.16

3.3.2 Coarse Aggregates

Crushed stone aggregate was the only type of coarse aggregate used in the project. The aggregates were acquired locally from Vulcan Materials, Chattanooga, TN. The aggregate sizes used in this study were ASTM C 33 #67 Stone, #7 Stone, and #89 Stone, and all met TDOT standards. All the coarse aggregates had bulk specific gravity of 2.74 and absorption of 0.62 %. Tables 3.5 shows the coarse aggregate grading for #67 Stone, #7 Stone, and #89 Stone respectively.

Table 0.5 Coarse Aggregate Gradation

Sieve Opening	Cumulative Percent Passing		
	#67 Stone	#7 Stone	#89 Stone
1 in.	100%	100%	100%
¾ in.	90%	100%	100%
½ in.	51%	99%	100%
3/8 in.	35%	80%	98%
NO. 4	8%	11%	39%
NO. 8	0%	1%	6%
NO. 100	0%	0%	0.5%
Pan	0%	0%	0%

3.3.3 Fine Aggregates

Two types of fine aggregate were used in this study that meet TDOT requirements which are natural and manufactured sand. The natural sand with specific gravity of 2.6 and an absorption rate of 1.3% acquired locally from Pine Bluff Materials, Nashville, TN**.** The manufactured sand with specific gravity of 2.74 and absorption rate of 0.64% was acquired locally from Vulcan Materials, Chattanooga, TN. The total amount needed for the project was acquired in one batch early in the project. The natural and manufactured sand gradations are shown in Tables 3.6.

Table 0.6 Fine Aggregates Gradation

Sieve Opening	**Cumulative Percent Passing**	
	Natural sand	**Manufactured sand**
3/8 in.	100.0%	100.0%
NO. 4	97.9%	99.6%
NO. 8	91.6%	78.2%
NO. 16	82.0%	45.1%
NO. 30	61.8%	26.4%
NO. 50	9.0%	13.0%
NO. 100	0.3%	5.0%
NO. 200	0.1%	2.0%
Pan	0.0%	0.0%

3.3.4 Chemical Admixtures

Two types of Admixtures used in the project, Mid-Range which was used for the conventional concrete and High-Range was used for SCC.

3.3.4.1 Mid-Range Water-Reducing Admixture

MasterPolyheed 900 produced locally by BASF Corporation was used as a Mid-Range Water-Reducing Admixture. It meets the requirements of ASTM C 494/C 494M for Type A, water-reducing admixtures. It is used to improve the workability of conventional concrete mixtures by attaining slump within the range of 3 to 5 inches without increasing the water cement ratio. The technical data sheet for Mid-Range water reducing admixtures was obtained from the supplier is summarized in Table 3.7.

Table 0.7 Technical Data of MasterPolyheed 900

Data	**Specification**
Initial Set time (hr:min)	5:18
Water reduction	9 - 10 %
Storage Temperature	35 to 105 °F
Minimum shelf life	18 months
Recommended dosage range	4 to 15 fl oz/cwt of cementitious materials

3.3.4.2 High -Range Water-Reducing Admixture

ADVA® Cast 575 was used as High range water reducing admixture. ADVA® Cast 575 is a high efficiency, low addition rate polycarboxylate-based high range water reducer designed for the production of a wide range of concrete mixtures, from conventional to Self-Consolidating Concrete. It is designed to impart extreme workability without segregation to the concrete. ADVA Cast 575 meets the requirements of ASTM C494 as a Type A and F, and ASTM C1017 Type I plasticizing agent. ADVA Cast 575 is supplied as a ready-to-use liquid that weighs approximately 8.9 lbs. /gal (1.1 kg/L). ADVA Cast 575 does not contain intentionally added chlorides.

3.3.5 Mixing water

Municipal tap water with temperature of 75 °F on average was used throughout the experimental mixtures.

3.4 Preparation of the Experimental Mixtures

This study was a part of TDOT project to develop Class-A SCC (general use) and Class-P (precast use). Class-P SCC mixtures were the mixtures selected for the study from the overall mixtures. A total of twenty four mixtures were performed during the study period. One mix was casted per day. As alluded earlier, sixteen from the overall mixtures selected for the study were SCC, and eight mixtures were conventional (normal slump) mixtures. Typically, a batch of four and a half cubic feet was prepared to provide concrete for the fresh and hardened property test samples of the SCC, and only three and quarter cubic feet of conventional concrete was required. Conventional concrete required a smaller batch due to the fewer fresh tests than the SCC.

Coarse and fine aggregate were stock piled in the courtyard of the EMCS building, accessible throughout rolling dock door from the concrete laboratory. Since the mixing process was performed during the winter, coarse and fine aggregates for one batch were brought inside the laboratory a day before to gain the room temperature. Aggregate moisture corrections were used to adjust the batch components (water and aggregates) before mixing to account for moisture condition of the aggregates. The moisture content of aggregate was calculated after weighing a representative sample from the aggregate pile before and after drying it using an electric heater. Appropriate weights of components according to the mix design were measured, adjusted, and then added together inside the nine cubic foot electric drum-type mixer.

After putting all the aggregates inside the mixer, two third of the adjusted amount of water was mixed together with the aggregates for one minute. Then the cement, fly ash and the rest of the water were added to the mix and mixed for three minutes. Appropriate amount of HRWRA was added gradually during the mix. After thorough mixing, the mixture was ready for taking the samples for fresh and hardened property tests of SCC and conventional concrete, as outlined in the testing protocol in Tables 3.8.

Table 0.8 Testing Protocol of SCC and Conventional Mixtures

Fresh Concrete Testing		**Test For**
Slump Test (ASTM C 143)	1 per batch	Conventional
Slump Flow and Visual Stability Index (ASTM C 1611)	1 per batch	Conventional and SCC
Consolidating ability by J-Ring (ASTM C 1621)	1 per batch	SCC
Static Segregation by Column Test (ASTM C 1610)	1 per batch	SCC
Unit Weight and Gravimetric Air Content (ASTM C 138)	1 per batch	Conventional and SCC
Air Content by Pressure Method (ASTM C 231)	1 per batch	Conventional and SCC
Time of setting of Concrete Mixtures by Penetration Resistance (ASTM C 403)	1-6.5*6.5 inch cylinder per batch	Conventional and SCC
Hardened Concrete Testing		
Compressive Strength (ASTM C 39)	2-6x12 inch cylinders per test time	Conventional and SCC
Static Modulus of Elasticity (ASTM C 469)	The 2-6x12 compressive strength cylinders will also be used for modulus per test time	Conventional and SCC
Splitting Tensile Strength (ASTM C 496)	2-6x12 inch cylinders per test time	Conventional and SCC

The hardened properties will be tested at 18 hours and 28 days only.

3.5 Fresh Property Tests

A number of fresh performance assessment tests were performed on the SCC and conventional mixtures during the study. The following tests were conducted to assess the fresh properties of SCC and conventional concrete.

3.5.1 Slump Test (ASTM C 143)

This was performed for the conventional concrete where a steel cone with base diameter of 8 inch and 4 inch in top diameter and height of 12 in was used. The test was carried out by filling the slump cone in three equal layers with the mixture being tamped down 25 times for each layer. The cone was removed from the concrete and the slump was measured. An example of slump test carried out is shown in Figure 3.1.

Figure 3.1 Slump Test

3.5.2 Slump Flow Test

The test was performed using the same cone used for the conventional concrete slump test. The cone was filed to the top with fresh SCC with the smaller opening facing down as shown in plate 1of Figure 3.2, while firmly holding the cone on the center of damped base plate. The cone was gently raised vertically in about four seconds as shown in plate 2 of Figure 3.2, forming a patty as shown in plate 3 of Figure 3.2. After the concrete stopped flowing the largest diameter of the patty was measured in two perpendicular directions as shown in plate 4 of Figure 3.2. The average value of the two diameters was recorded as the slump flow diameter. The range of slump flow according to ACI Committee 237 was kept between 18 to 30 inches.

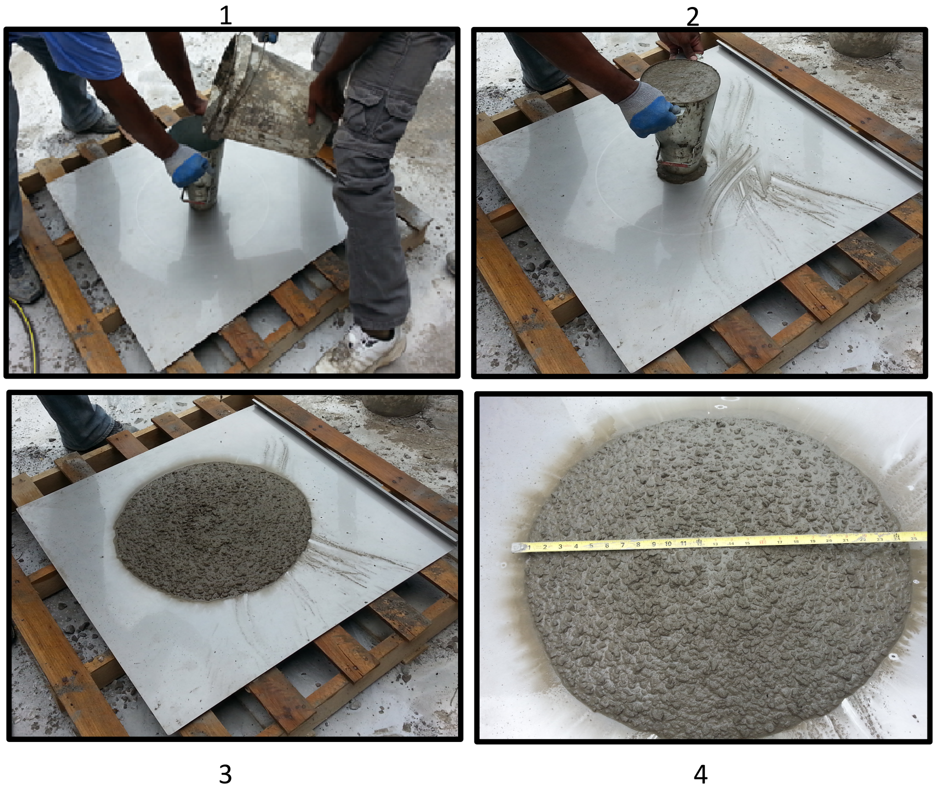
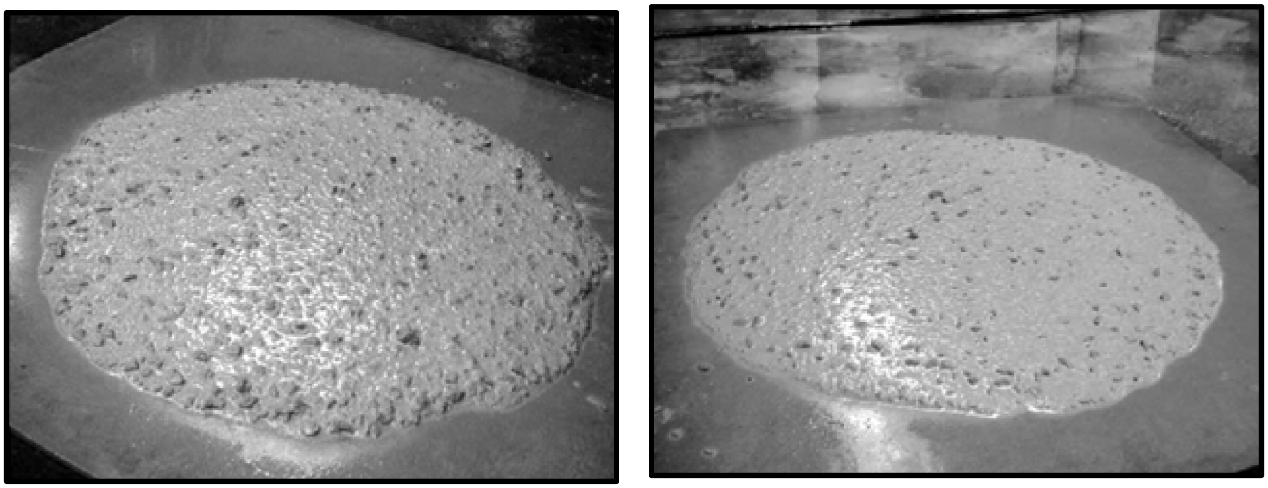


Figure 3.2 The Slump Flow Test

3.5.3 Visual Stability Index

The VSI required for the mixtures in this project were VSI of 1 and 2. VSI was determined through visually rating the apparent stability of the slump flow patty based on specific visual properties of the spread patty. The desirable VSI values were achieved by varying the amount of HRWR used during mixing. Values of VSI of 1 and 2 were recorded according to (ASTM C1611/C1611M) as shown in Figure 3.3.



VSI = 1 – No evidence of segregation and slight bleeding observed as a sheen on the concrete mass

VSI = 2 – A slight mortar halo # 0.5 in.(# 10 mm) and/or aggregatepile in the of the concrete mass

Figure 3.3 Visual Stability Index Criteria

3.5.4 T-50

The T-50 value was used to assess the flowing ability of SCC, and to provide a relative index of the viscosity. The test value was measured during the slump flow test. The value was obtained by measuring the time from lifting the cone that filled with concrete to the concrete paddy to reach a diameter of 20 in (50 cm) as shown respectively in plates 1, 2 and 3 of Figure 3.4.

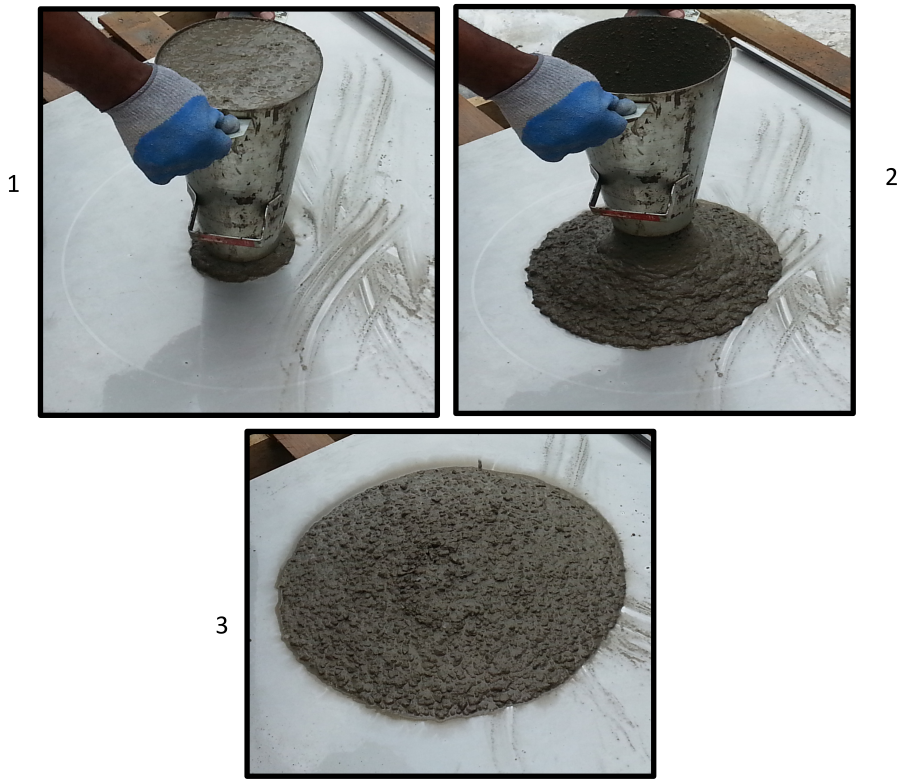


Figure 3.4 T-50 Measurement

3.5.5 J-Ring Test

A cone filled with fresh SCC was placed inside the J-ring base. The cone was held to the center of damped base plate with the smaller opening facing down as shown in plate 1 of Figure 3.5. The cone was then raised as shown in plate 2, the SCC passed through J-ring as shown in plate 3, and the average of diameters of the concrete paddy measured in two perpendicular directions was recorded as the J-ring flow diameter as shown in plate 4. An example of a J-Ring test is shown in Figure 3.5.

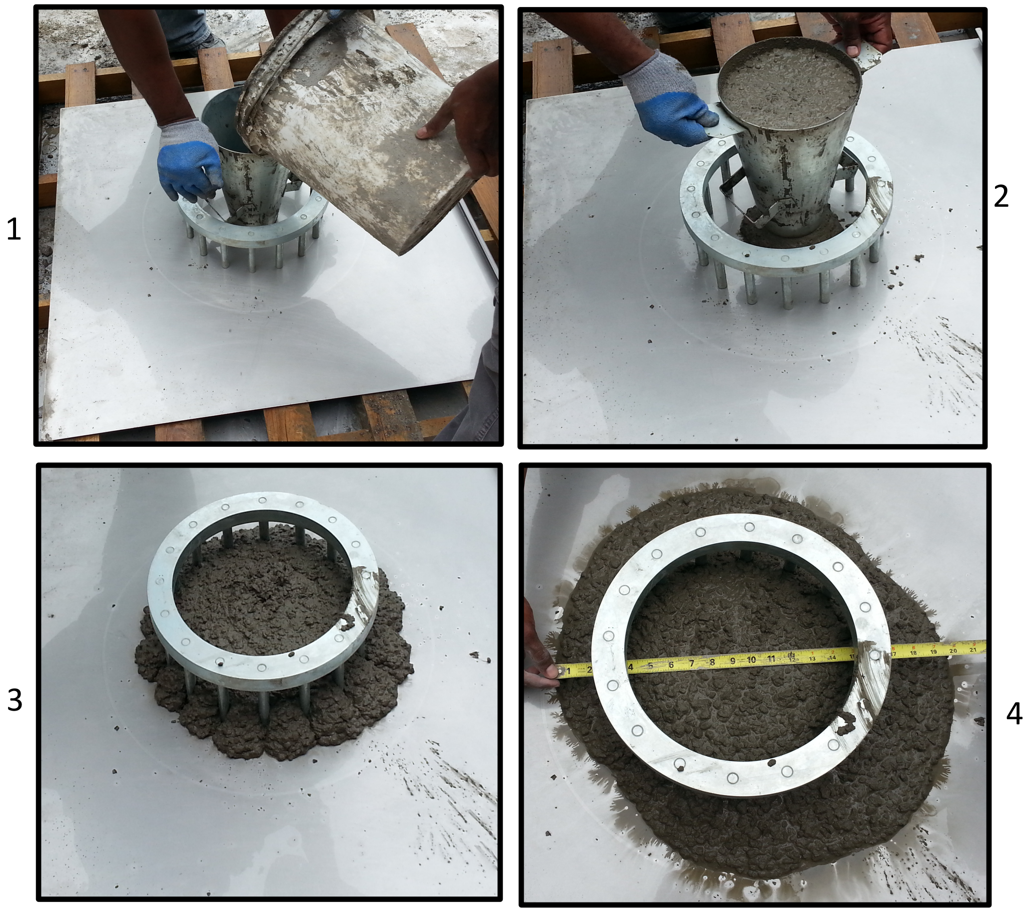


Figure 3.5 J-Ring Test Procedure

3.5.6 L-Box Test

L-Box test was used to evaluate the passing ability of the SCC mixtures. The SCC was poured in the vertical section of the L-box apparatus to its full height as shown in plate 1 of Figure 3.6; the top of the section was struck off using the strike-off bar, to remove any excess materials. The gate was lifted up and enabling the concrete to flow into the horizontal section as shown in plate 3 and plate 4 of Figure 3.6. When the flow stopped, the heights of the concrete were measured at the end of the horizontal section and the vertical section. The L-Box result is the ratio of the height of concrete in the horizontal section to remaining in the vertical section. An example of L-Box testing is shown in Figure 3.6.

Figure 3.6 L-box Test

3.5.7 Column Segregation

Column segregation was used to assess the fresh coarse aggregate segregation from the mortar fraction on the SCC mixtures. The test was conducted by filing a 26 inch column that is divided into three sections with fresh SCC. After filling the column with SCC as shown in plate

1 of Figure 3.7 the concrete was let to rest for 15 minutes as shown in plate 2 of Figure 3.7. After that each section was removed using a cutting plate, and the concrete in the top and the bottom section were washed over No. 4 sieve leaving only the aggregates, and the retained aggregates were weighed. The two weights was recorded to calculate the percentage of segregation using equation 3.1. An example of the column segregation test apparatus is shown in Figure 3.7

$$S = 2\left[\frac{(CA_B - CA_T)}{(CA_B + CA_T)}\right] * 100\,, if\ CA_B > \ CA_T \ \ldots \quad \text{Equation 0.1}$$

$$S = 0, if CA_B \leq \ CA_T$$

Where:

S = static segregation, percent.

CA_T = mass of coarse aggregate in the top section of the column.

CA_B = mass of coarse aggregate in the bottom section of the column.

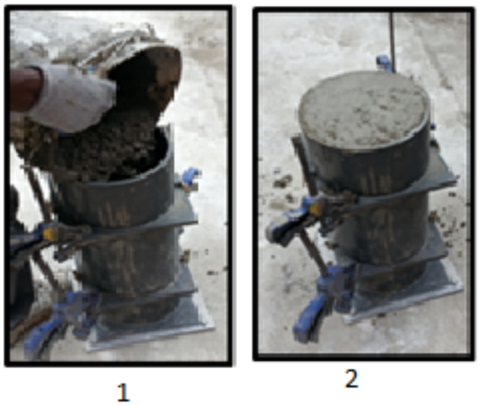


Figure 3.7 The Static Column Segregation

3.5.8 Unit Weight of Fresh Concrete

This test was conducted to determine the density of freshly mixed conventional concrete and SCC, in accordance with the ASTM C 138 standards. The main apparatus is a cylindrical container made of steel with 8 in diameter and 8.5 in height. The test was carried out for conventional concrete by filling the cylinder mold in three equal layers with the mixture being tamped down 25 times for each layer with a tamping rod, and then the sides of the measure were tapped about 10 times using rubber mallet. The top of the mold was then stuck off using the strike-off bar, to remove excess materials and cleaned from the outside. The same process was conducted for the SCC mixtures, but the concrete was poured in one layer without rodding or tapping. The mass of the mold and concrete were then determined, and the density was calculated using the equation 3.2.

$$D = \frac{M_c - M_m}{V_m} \text{ ....Equation 0.2}$$

Where:

D = density (unit weight) of concrete, lb. /ft^3

M_c = mass of the measure filled with concrete, lb.

M_m = mass of the measure, lb.

3.5.9 Air Content by Pressure Method

This method was used to determine the air content of freshly mixed conventional concrete and SCC through the observation of the change in volume of concrete with a change in pressure, in accordance with the ASTM C 231 standards. The main apparatus is a Meter type B which is the same cylinder used to measure the unit weight plus a cover assembly which is fitted with a pressure gauge, air valves, and petcocks for bleeding off. The test was carried out for conventional concrete by filling the cylinder mold in three equal layers with the mixture being tamped down 25 times for each layer with a tamping rod, and then the sides of the measure were tapped about 10 times using rubber mallet. The top of the mold was then stuck off using the strike-off bar, to remove excess materials and cleaned from the outside as shown in plates 1 and 2 of Figure 3.8. The same process was conducted for the SCC mixtures, but the concrete was poured in one layer without rodding or tapping. After that, the cover assembly was placed and clamped, the main air valve was closed, and both the petcocks thought the cover were opened. Clean water was injected through one petcock until the water emerged from the other petcock with no bubbles to ensure there is no bubbles inside. After that, the air bleeder valve was closed, and the air was pumped into the air chamber until the gauge reached the initial pressure calibration of the equipment. Eventually, the main air valve was released, and the percentage of air was read on the dial of the pressure gauge. An example of the air content test is shown in Figure 3.8.

Figure 3.8 Air Content Test

3.6 Curing of Concrete

In order to achieve the strength requirements for Class-P concrete of attaining 4000 psi in eighteen hours accelerated curing was used. After completing the fresh concrete tests a batch with twelve plastic molds of concrete were placed inside the SURE CURE curing cylinders for six hours. The SURE CURE molds were attached to mini controller which worked as median between the computer and the molds as shown in plate 1, 2 of Figure 3.10. The mini controller provided the SURE CURE cylinder molds with electrical current which was input by the computer as shown in plate 3 of Figure 3.10. The SURE CURE molds transform the current transmitted from the mini controller to a heat using the coils imbedded inside the molds. After six hours the system was switched on to apply a temperature of between 80°F and 155 °F for twelve hours. The rate of temperature increments was set to be less than 50 °F per hour to avoid cracking as shown in Figure 3.9. Plant Manager Software developed by SURE CURE systems was used to track the molds temperature during the curing cycle. A temperature profile was entered using Set Cure cycle Software. The SURE CURE equipment were acquired from Products Engineering based in Evergreen, CO. At the end of the cycle the concrete cylinders were removed from their molds. Four of the concrete cylinders removed were used for the 18 hours hardened properties tests and the other eight cylinders were stocked in a basin filled with normal water to cure at temperature 70 +/- 2 °F. An example of the SURE CURE system was shown in Figure 3.10.

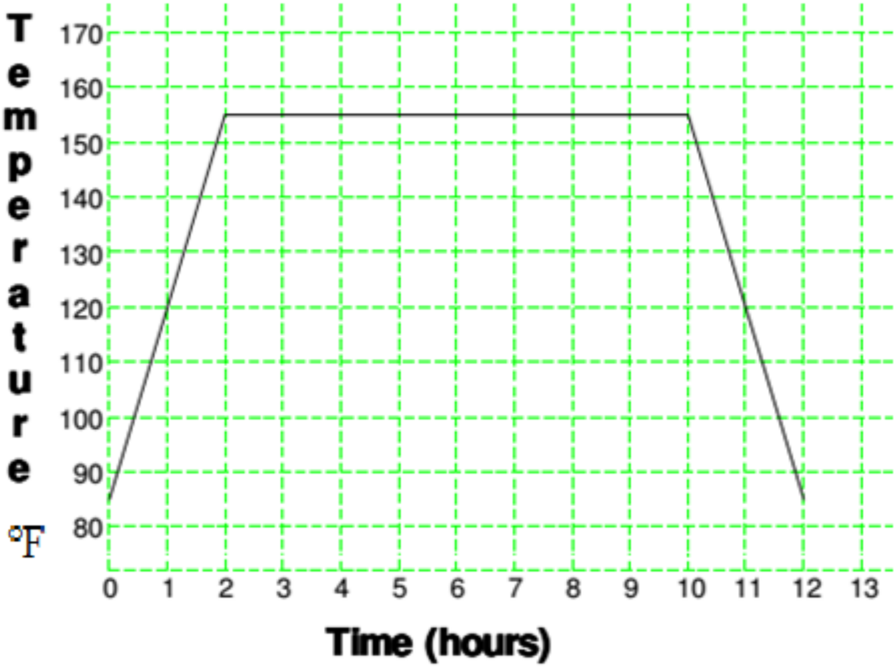


Figure 3.9 Temperature Profile of the Curing Cycle

Figure 3.10 SURE CURE System Equipment

3.7 Hardened Properties Tests

A number of tests were conducted to assess the hardened properties of conventional concrete and SCC mixtures. The same tests were performed for the both types of mixtures as follows.

3.7.1 Compressive Strength (ASTM C 39)

Compressive strength test was performed for both SCC and conventional concrete. Each batch was tested after 18 hours, 28 days and 56 days. Two samples were used to conduct the compressive strength test using a Humboldt compression Machine. The sample was properly aligned inside the machine. A load increments of 5000 lbs. /sec was subjected to the sample until failure. This failure point was recorded as the compressive strength of the sample. The same procedure was repeated for all the tested samples. An example of compression test was shown in Figure 3.11.

Figure 3.11 Compressive Strength Test

3.7.2 Static Modulus of Elasticity (ASTM C 469)

The test was performed for both SCC and conventional concrete. Two samples were selected for the test. The samples were tested using a Humboldt compressometer and a Forney calibrated load frame. The samples were loaded to approximately 40% of the ultimate concrete strength obtained from the compressive strength test. Two readings were required to get the Modulus of Elasticity using Equation 3.3. An example of this test sample was shown in Figure 3.12.

$$E=\frac{(\sigma_2-\sigma_1)}{(\varepsilon_2-0.00005)} \text{ ....Equation 0.3}$$

Where:

E=chord modulus of elasticity (in psi)

σ_2=stress corresponding to 40% of the ultimate load of the concrete (in psi)

σ_1=stress corresponding to a longitudinal strain of ε_1 at 50 millionths (in psi)

ε_2=longitudinal strain produced by σ_2

Figure 3.12 Modulus of Elasticity Setup

3.7.3 Splitting Tensile Strength (ASTM C 496)

Splitting Tensile strength test was used to determine the tensile strength of SCC and conventional concrete. The sample was placed horizontally between the compressive strength machine and the loading surface as shown in Figure 3.13. The compression was applied diametrically and uniformly along the length of the cylinder until failure. The failure was indicated by a longitudinal crack on the sample. The load increment rate was 300 lbs. /sec. The failing point was recorded. An example of the test was shown in Figure 3.13.

Figure 3.13 Splitting Tensile Strength Test

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The fresh and hardened properties of the 24 class-P SCC mixtures are presented in the chapter. The hardened properties tests presented in the study are 18 hours and 28 days tests. The representation of the results are shown as a comparison between VSI 1 and VSI 2 for both fresh and hardened properties since the main objective of the study is to investigate the effect of VSI. The correlations between these mixtures using different aggregate sizes (#67 stone, #7 stone, and #89 stone, natural and manufactured sand) and fly ash class F are presented and discussed. In this chapter every fresh and hardened property is discussed against the VSI which correlate to the Cementious content used (Ordinary Portland Cement (OPC) against cement plus Class F fly ash).

4.2 Experiments Results

A total of 24 mixtures were produced as designed in chapter 3. The mixtures were comprised of 16 SCC mixtures and 8 conventional mixtures. The conventional mixtures were included to serve as control mixtures. A number of fresh and hardened properties were tested to assess the performance of the mixtures. The fresh property test performed on the conventional concrete was the Slump test. While SCC were tested Slump flow, T-50, L-box ratio, J-ring test, and the Fresh Column segregation test. The initial and final times of set and Air entrained values were recorded for both SCC and conventional concrete. The results of the fresh properties test are presented in Table 4.1 for the different aggregate sizes (#67 stone, #7 stone, and #89 stone, natural and manufactured sand) used.

The hardened properties tests performed were compressive strength test, tensile strength test and the modulus of elasticity. The hardened properties tests were recorded for 18 hours and 28 days tests. The results of the hardened properties tests are shown in Table 4.2 for the different aggregate sizes (#67 stone, #7 stone, and #89 stone, natural and manufactured sand) used. Compressive strength results highlighted with red color in Table 4.2 means that the value is less than 4000 psi which is the TDOT requirements for the compressive strength to be in the 18 hours test. The first 12 mixtures in every Table were produced with only portland cement as the sole Cementious materials, while the mixtures from mix number 13 until mix number 24 were produced with Class F fly ash as 20% of the total Cementious materials required and the rest 80% was portland cement. Each of the Tables were divided by a thick horizontal line to separate the fly ash mixtures from the OPC mixtures. Later in the chapter the values obtained from the experiments are compared to VSI 1 and VSI 2 to study the effect of VSI on the fresh and hardened properties which correlate to Class F fly ash and OPC.

Table 0.1 The Results of Fresh Properties Tests

													Time of Set (hr:min)	
Mix	**Casting date**	**VSI**	**Slump (in)**	**J-ring (in)**	**Dif. (in)**	**HRWR (oz./cwt)**	**Temp (F)**	**Air (%)**	**T-50 (sec.)**	**Unit weight (lb./ft3)**	**L-box (ratio)**	**Col. Seg (%)**	**Initial**	**Final**
1	2/10/2015	1	19	17	2	2.99	75	3.60%	1.5	142.9727	0.000	9.2%	6:00	8:50
2	2/24/2015	2	25	21	4	3.89	75	4.70%	0.57	141.3549	0.462	23.3%	7:15	8:30
3	2/9/2015	Conv.	5.25			0.00	77	3.40%		0			4:58	6:25
4	3/10/2015	1	22.5	17.5	5	3.44	76	5.30%	3.09	144.186	0.000	15.0%	6:30	7:55
5	3/14/2015	2	24.75	19.75	5	6.58	76	1.50%	3.07	148.0283	0.000	7.7%	5:15	6:57
6	2/5/2015	Conv.	3.25			6.21	75	3.90%		0			5:30	7:15
7	1/30/2015	1	23	18.75	4.25	4.49	76.4	3.10%	4	143.3771	0.000	12.3%	6:37	8:15
8	1/31/2015	2	25.5	24	1.5	6.88	75.4	1.80%	2.9	145.3994	0.043	18.2%	7:52	9:50
9	1/29/2015	Conv.	3			10.36	76	3.60%		0			6:25	8:45
10	2/28/2015	1	20.5	16	4.5	4.19	71	6.20%	4.46	139.1304	0.000	10.1%	7:05	8:53
11	3/3/2015	2	22.5	18.25	4.25	5.09	73	5.60%	3	139.9393	0.000	8.3%	6:30	8:12
12	2/25/2015	Conv.	3.5			4.14	75	3.00%		0			6:05	7:57
13	3/24/2015	1	23	18.75	4.25	7.18	75	5.60%	2.94	143.1749	0.267	1.3%	6:30	7:20
14	3/30/2015	2	26.5	25	1.5	8.68	75	4.30%	1.31	145.3994	0.875	20.9%	7:33	9:00
15	3/23/2015	Conv.	5			0.00	68	2.20%		0			6:25	7:55
16	4/1/2015	1	23	18	5	9.28	76	3.20%	5.97	143.3771	0.000	20.3%	7:20	9:17
17	3/31/2015	2	25	21.75	3.25	11.37	76	3.20%	4.69	144.9949	0.000	9.7%	7:00	8:30
18	4/20/2015	Conv.	4.25			6.21	74	3.10%		0			5:35	7:20
19	4/12/2015	1	20	18.25	1.75	3.39	76	4.40%	1.42	147.0172	0.240	8.0%	6:35	8:15
20	4/10/2015	2	28.25	28	0.25	3.59	75	2.40%	0.6	143.5794	0.885	16.4%	8:27	10:00
21	4/7/2015	Conv.	4			0.00	74	3.20%		0			6:54	8:45
22	4/14/2015	1	19	17	2	1.80	77	6.10%	1.82	140.546	0.000	10.1%	6:20	8:17
23	4/22/2015	2	25	24.5	0.5	4.49	74	7.10%	1	139.1304	0.529	14.8%	7:20	8:40
24	4/8/2015	Conv.	2			4.97	76	3.60%		0			6:15	7:20

Table 0.2 The Results of Hardened Properties Tests

		18-hrs			28 days		
Mix	**VSI**	**Comp. (psi)**	**Tensile. (psi)**	**E. (ksi)**	**Comp. (psi)**	**Tensile. (psi)**	**E. (ksi)**
1	1	3540	360	4850	5580	460	5222
2	2	3830	255	5740	6310	351	4940
3	Conv.	3250	276	4972	5700	310	6063
4	1	4380	272	5093	6310	452	4827
5	2	5140	390	5618	7080	477	4757
6	Conv.	4405	338	4981	7015	457	8046
7	1	5005	254	4163	7280	386	6467
8	2	5185	289	4850	7750	398	6548
9	Conv.	4455	391	5174	7185	406	6467
10	1	4615	359	6871	6610	428	4975
11	2	4710	356	4293	7105	370	6007
12	Conv.	4250	341	4238	6230	298	5337
13	1	4825	304	4320	7360	536	5206
14	2	4640	322	7996	6225	457	5340
15	Conv.	2835	232	3537	6860	441	6013
16	1	3270	270	3442	5505	414	5128
17	2	3875	358	3125	6780	447	5908
18	Conv.	3335	261	4005	5860	435	5293
19	1	2520	190	3395	5205	385	4357
20	2	1845	205	3601	5010	341	4258
21	Conv.	3145	214	4378	5950	464	4980
22	1	2460	294	3631	4950	340	3858
23	2	2710	186	3229	5165	313	4341
24	Conv.	3565	259	4514	6490	345	5047

Conv. is a representation for conventional concrete

4.3 Discussion of Fresh Properties of Concrete Mixtures

4.3.1 Filling Ability Property

The filling ability of the SCC was assessed with the Slump flow test and T-50 values. Slump flow values vary proportionally with VSI value as shown in Figure 4.1. VSI 1 and VSI 2 were achieved by using different HRWR dosages as shown in Figure 4.2, and determined by a visual rating of the slump flow patty as mentioned in chapter 3. T-50 values were measured to provide a relative index for the viscosity. Slump flow and Slump values are shown in Figure 4.1, while T-50 values are shown in Figure 4.3.

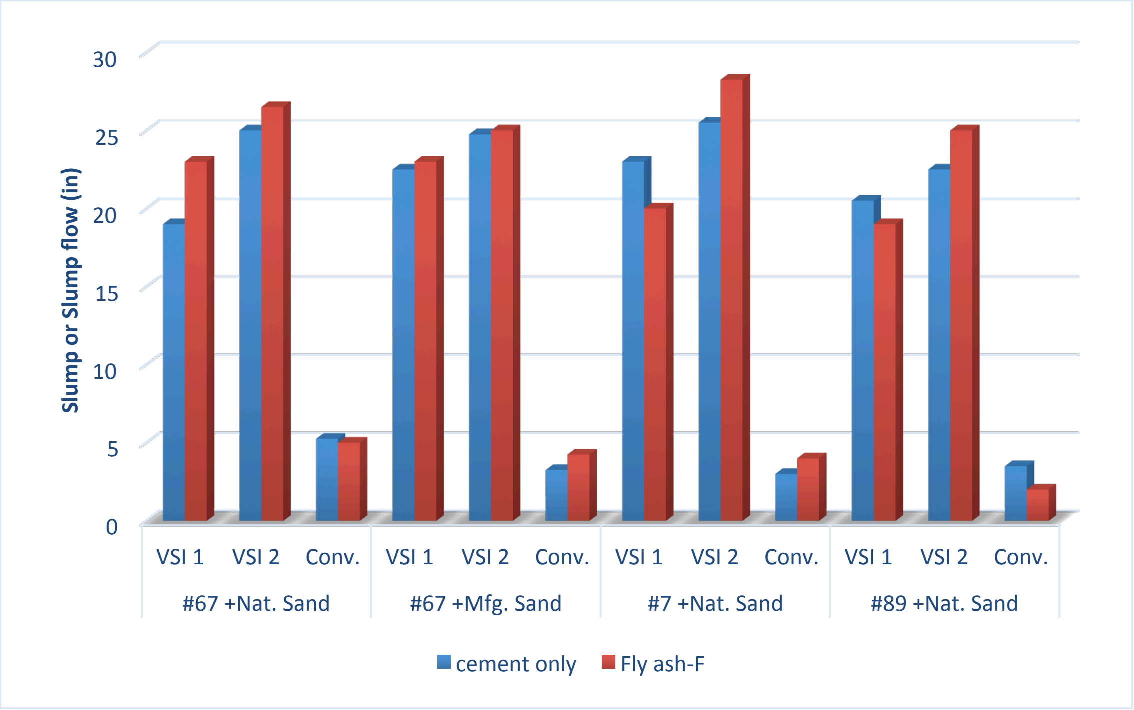


Figure 4.1 Slump and Slump Flow of the Studied Mixtures

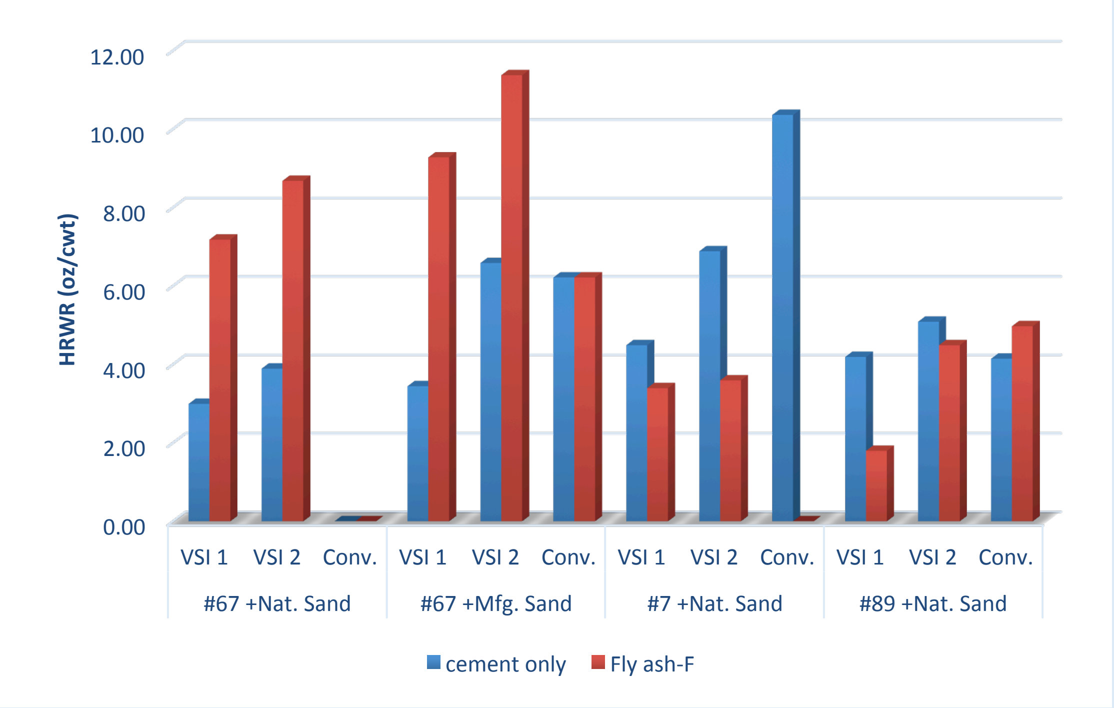


Figure 4.2 Water Reducer Admixture Requirements for the Studied Mixtures

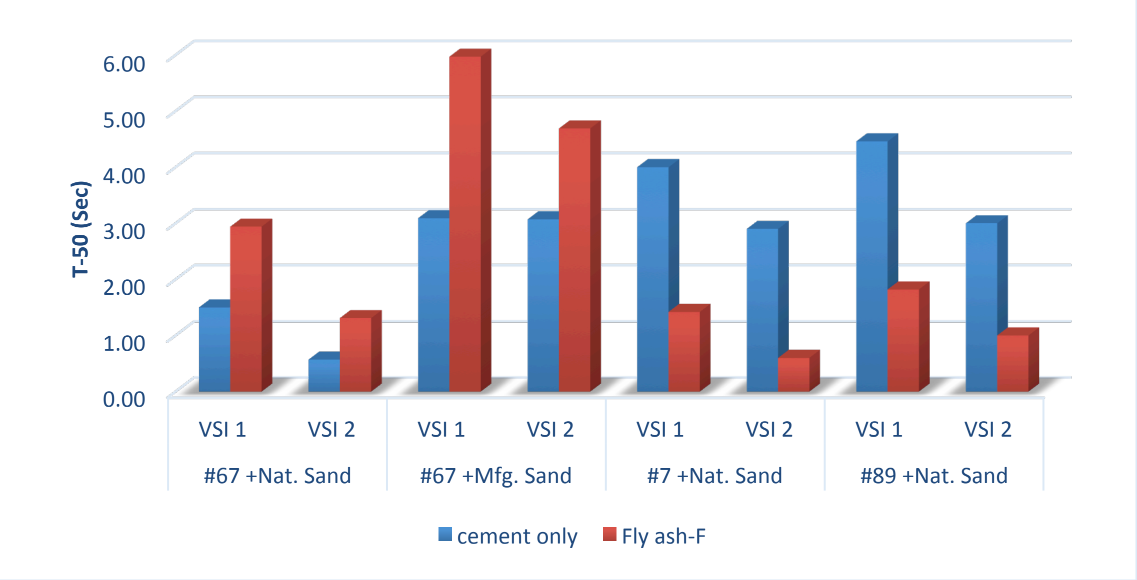


Figure 4.3 T-50 Results of the Studied Mixtures

4.3.1.1 Mixtures Containing Coarse Aggregate #67 with Natural and Manufactured Sand

Coarse aggregate #67 was used to a total of 12 mixtures, eight SCC and four conventional concrete. Half of the mixtures were developed using natural sand, three of them (Mix No 1, 2, and 3) were produced only with portland cement, and the other three (Mix No 13, 14, and 15) were produced using 20% cement replacement with Class F fly ash. Manufactured sand was used with the same criteria of the natural sand on the other half of the mixtures (Mixtures No 4, 5, 6, 16, 17 and 18).

The slump flow values and water reducer admixture requirements were summarized in Figures 4.4 and 4.5. As can be seen from Figure 4.4, all SCC mixtures have slump flow range between 19 to 26.5 inches, and the mixtures with the VSI of 2 show higher slump flow than that of the VSI of 1. Mixtures made with natural sand has a higher slump flow values compared to the ones made with manufactured sand as shown in Figure 4.4, and at the same time the amount of HRWR added to the manufactured sand is higher than the one added to the natural sand as shown in Figure 4.5.

This behavior could be attributed to the particle gradation and shape difference between the natural and manufactured sand. It should be noted that the OPC mixtures exhibit a slightly higher slump flow in both conventional and SCC with a VSI of 2 than Class F fly ash mixtures, however that class F fly ash mixtures have a greater HRWR dosages.

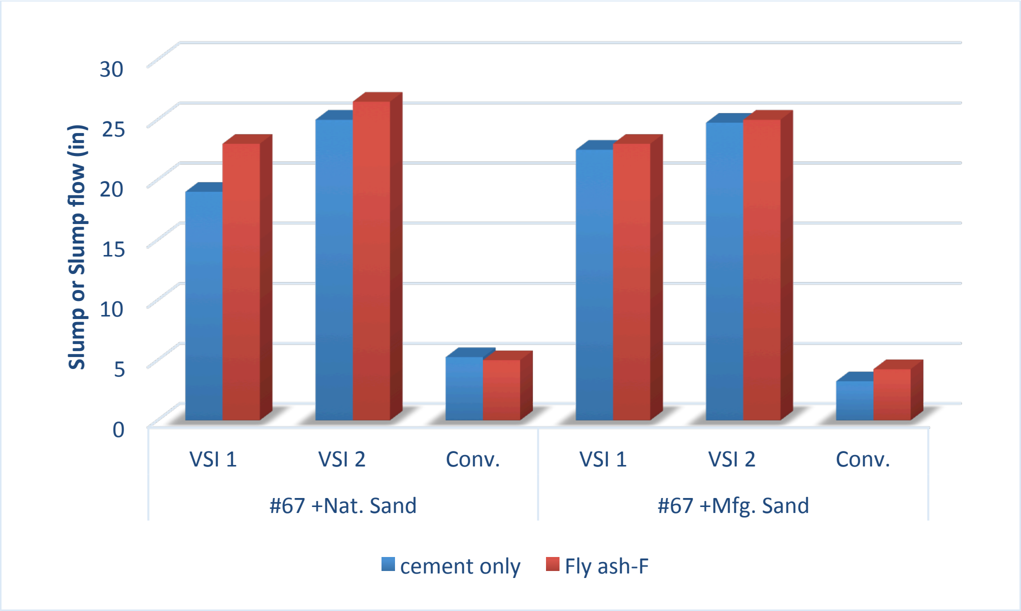


Figure 4.4 Slump and Slump flow of #67 Stone Mixtures

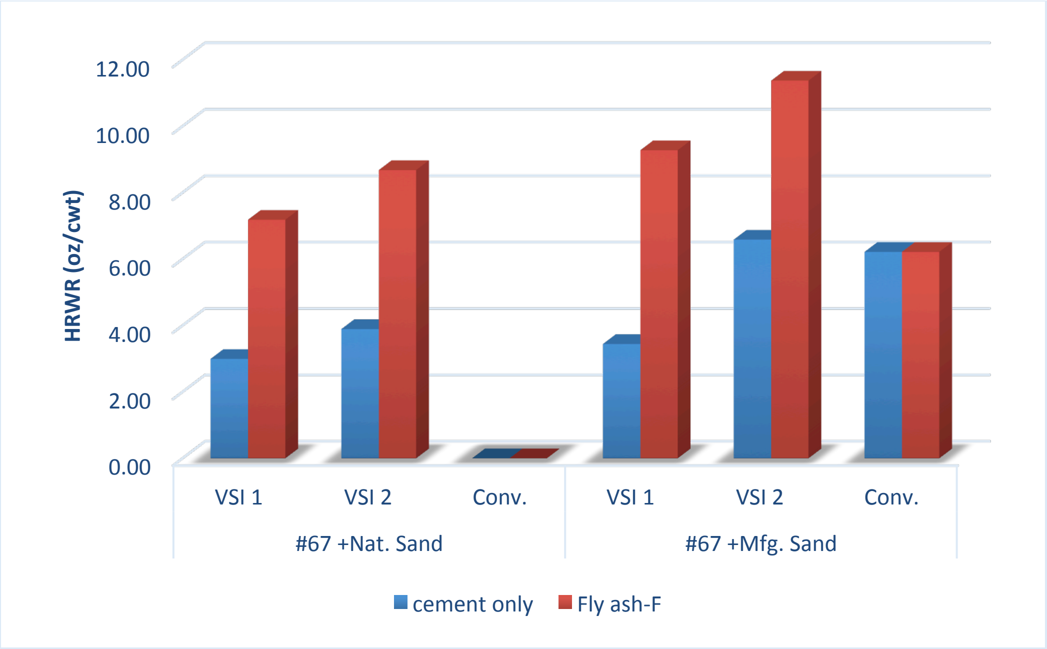


Figure 4.5 Water Reducer Admixture Requirements for #67 Stone Mixtures.

As shown in Figure 4.6 that the mixtures containing natural sand show lower viscosity than that containing manufactured sand. This behavior could be attributed to the particle gradation and shape difference between the natural and manufactured sand; the natural sands tend to be rounded shape whereas manufactured sands tend to be angular. It is also obvious that the mixtures with the fly ash Class F is showing higher viscosity (higher T-50) compared to the OPC mixtures.

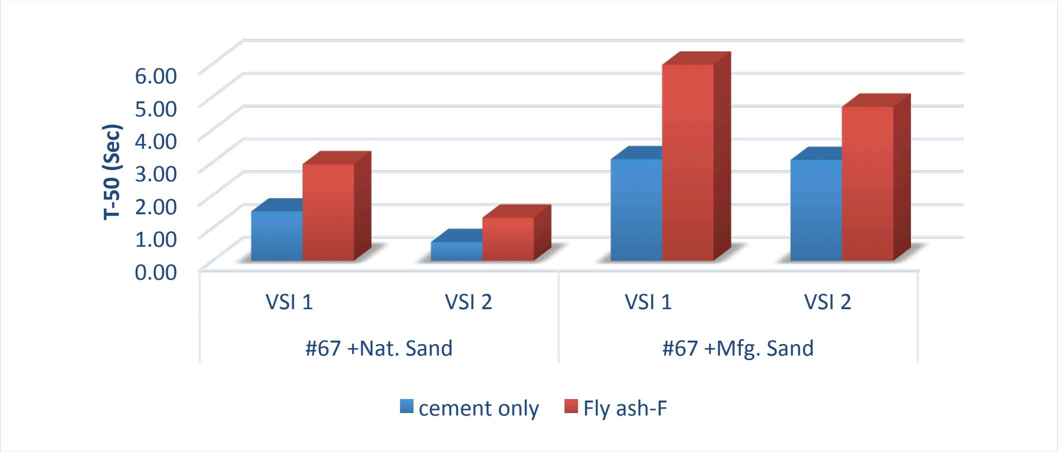


Figure 4.6 T-50 Values of #67 Stone Mixtures

4.3.1.2 Mixtures Containing Coarse Aggregate #7 with Natural Sand

Coarse aggregate #7 has a maximum aggregate size of 0.5 in. A total of six mixtures (Mix No 7, 8, 9, 19, 20, and 21) two SCC with VSI 1, two SCC with VSI 2 and two conventional, were produced using natural sand. The slump flow values, water reducer admixture requirements, and the T50 values are summarized in Figures 4.7, 4.8, and 4.9 respectively. From Figure 4.7 it is obvious that all SCC mixtures have slump flow within the range of 20 - 30 in. Slump flow results seems to be higher for VSI 1 using OPC than fly ash mixtures, while the opposite is true when producing VSI 2 as shown in Figure 4.7. Also it is clear in Figure 4.7, Class F fly ash mixtures show a higher slump compared to OPC in conventional mixtures, although the amount of WRA used in the OPC mixtures is higher than used in fly ash mixture. HRWR dosages used with #7 stone are generally lower than the ones used with #67 stones.

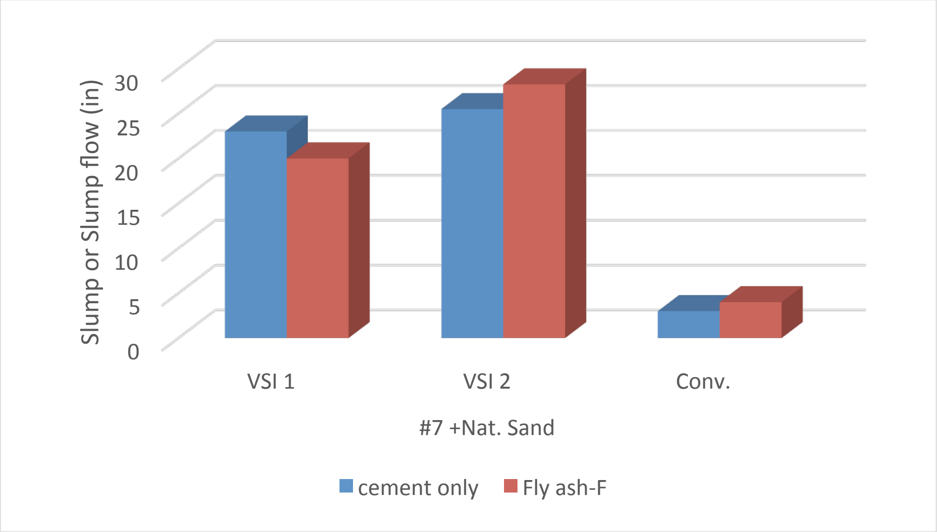


Figure 4.7 Slump and Slump Flow of #7 Stone Mixtures

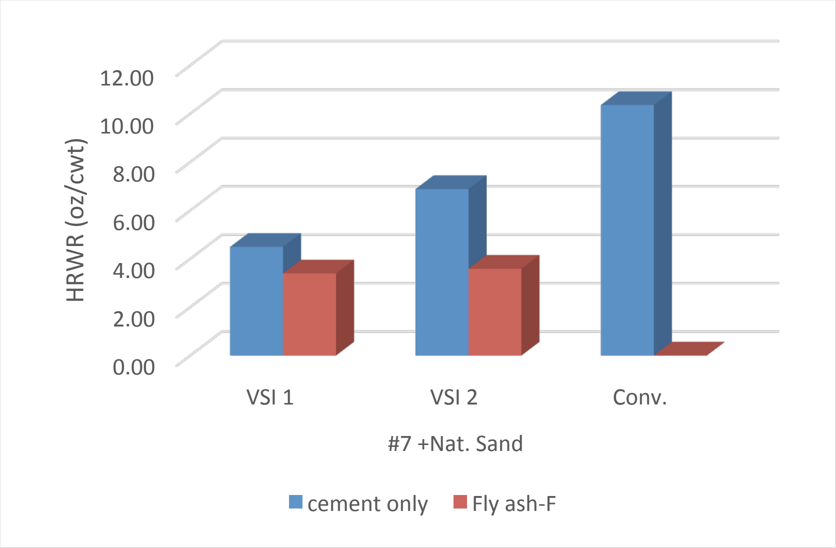


Figure 4.8 Water Reducer Admixture Requirements For #7 Stone Mixtures

The same phenomena of #67 stone with the natural sand, the Class F fly ash mixtures show shorter T-50 time than that of the OPC mixtures as shown in Figure 4.9, which is due to the high dosages of HRWR that was added to Class F fly ash mixtures to attain the desirable VSI values.

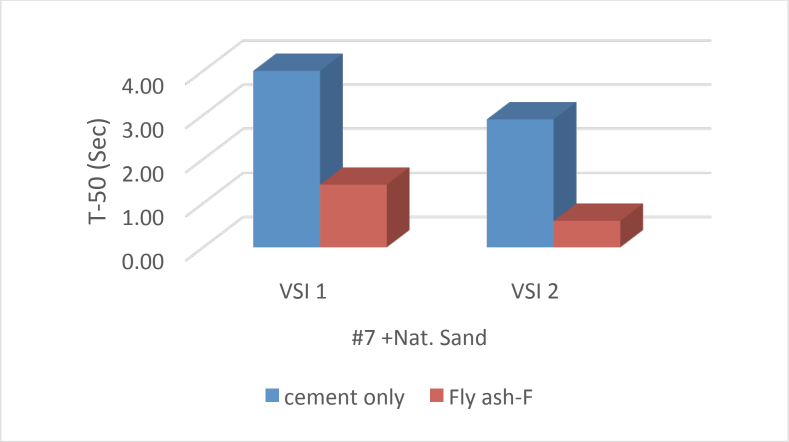


Figure 4.9 The T-50 Values of #7 Stone Mixtures

4.3.1.3 Mixtures Containing Coarse Aggregate #89 with Natural Sand

Coarse aggregate #89 was used in this study with natural sand only. Also it was the smallest aggregate size used in this study. A total of six mixtures (Mix No 10, 11, 12, 22, 23, and 24) two SCC with VSI 1, two SCC with VSI 2 and two conventional, were produced using natural sand. The slump flow values, water reducer admixture requirements, and the T50 values are summarized in Figures 4.10, 4.11, and 4.12 respectively. From Figure 4.10 it is obvious that all SCC mixtures have slump flow within the range of 19 - 25 in. The same phenomena with #7 stone that Slump flow results seems to be higher for VSI 1 using OPC than fly ash mixtures, while it is the opposite is true when producing VSI 2 as shown in Figure 4.10. Also it is clear in Figure 4.10, using Fly ash Class F shows higher slump in the conventional than the mixtures made with OPC, although the amount of WRA used in the OPC mixtures are higher than used in fly ash mixture. HRWR dosages used with #89 stone are generally lower than the ones used with #67 stones and #7 stones.

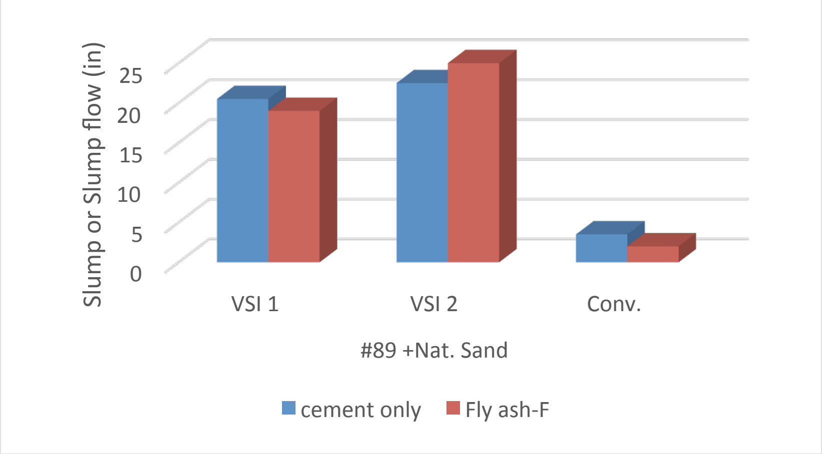


Figure 4.10 Slump and Slump Flow of #89 Stone Mixtures

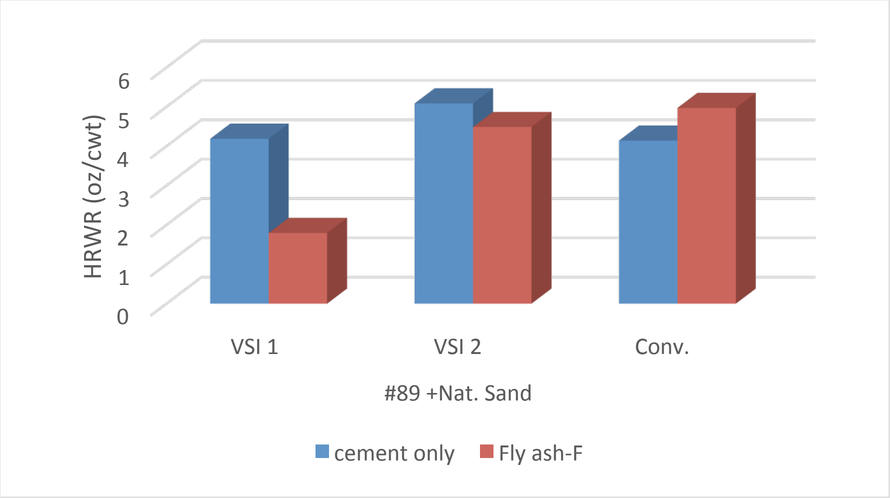


Figure 4.11 Water Reducer Admixture Requirements for #89 Stone Mixtures

The same phenomena of #67 stone with the natural sand and #7 stone, the Class F fly ash mixtures show shorter T-50 time than that of the OPC mixtures as shown in Figure 4.12, which is due to the high dosages of HRWR that was added to Class F fly ash mixtures to attain the desirable VSI values.

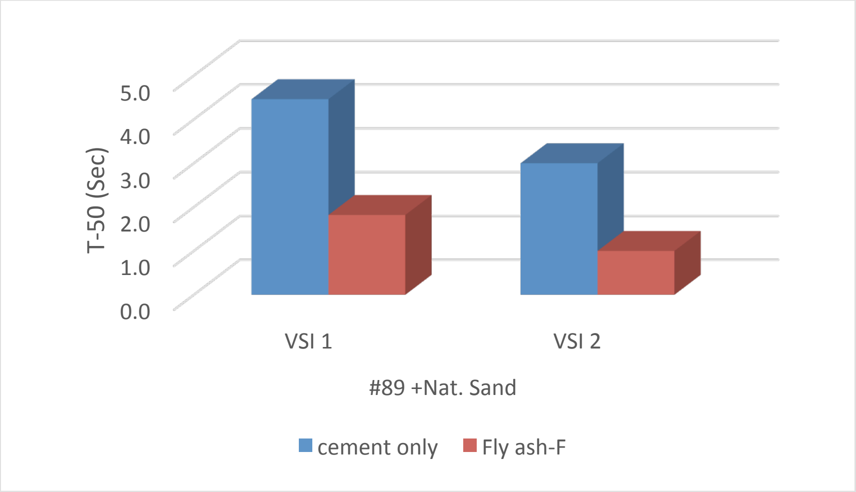


Figure 4.12 The T-50 Results of #89 Stone Mixtures

4.3.2 Passing Ability of SCC Mixtures

The passing ability property was assessed as mentioned earlier by conducting the J-ring and L-box tests on the studied mixtures. ASTM C1621 standards classify the blocking tendency for J-ring results as shown in Table 4.3, while The ACI 237 committee report recommends the L-box ratio close to the 1.0 as better passing ability. The results of J-ring and L-box tests were obtained for different aggregate sizes are summarized in Figures 4.13 and 4.14.

Table 0.3 Blocking Assessment Using J-ring

Difference Between Slump Flow and J-Ring Flow	0 to 1 in.	>1 to 2 in.	>2 in
Blocking Assessment	No visible blocking	Minimal to noticeable blocking	Noticeable to extreme blocking

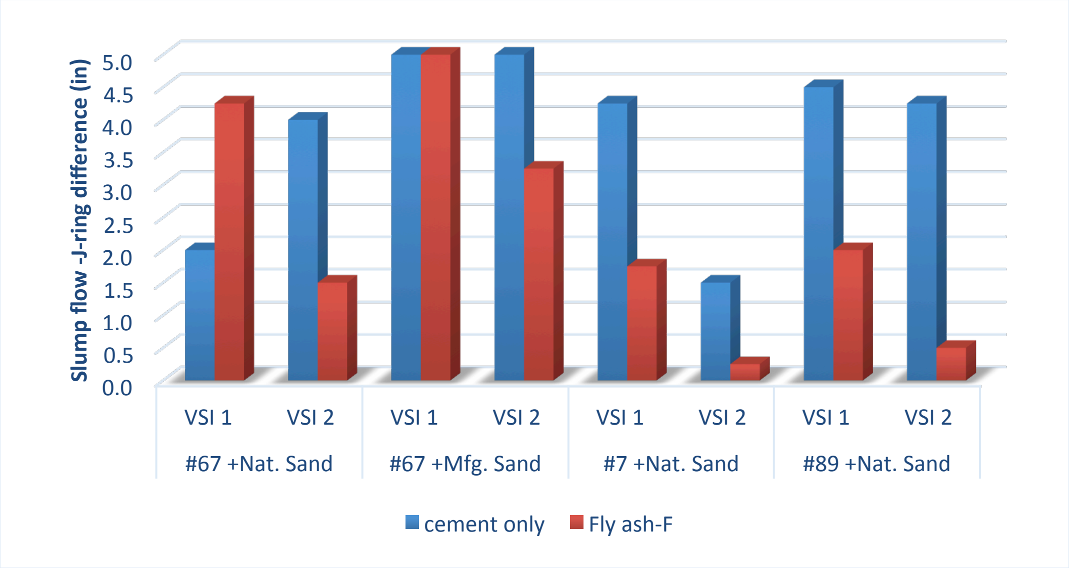


Figure 4.13 Slump Flow and J-ring Difference for the Studied SCC by Coarse Aggregate Type

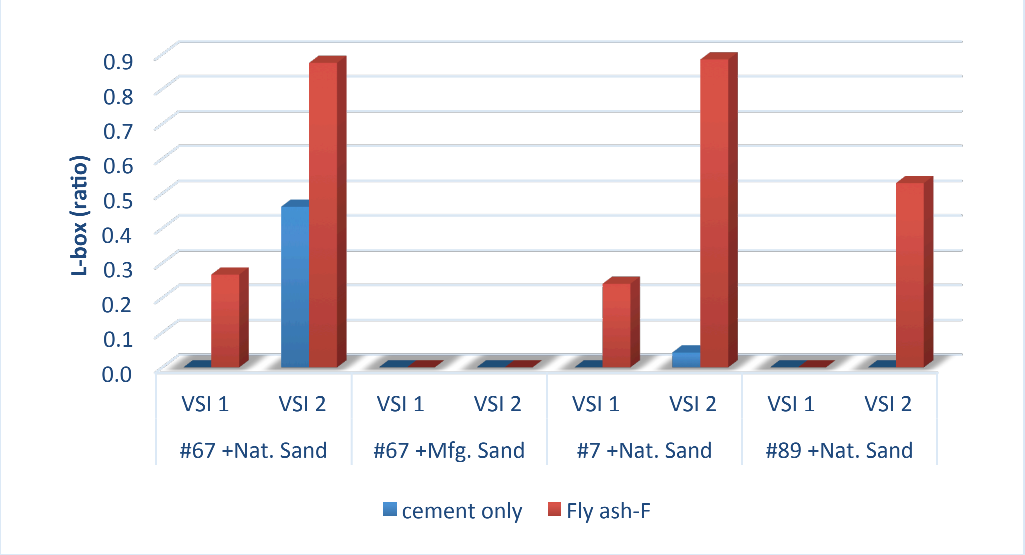


Figure 4.14 The L-Box Ratio for the Studied Mixtures

4.3.2.1 Mixtures Containing Coarse Aggregate #67 with Natural and Manufactured Sand

The passing ability of the manufactured sand is very poor compare to the natural sand as shown in Figure 4.15, especially in the VSI of 1 mixtures. Mixtures with Class F fly ash has a better passing ability than OPC mixtures when producing VSI of 1 mixtures, while OPC mixtures has a better passing ability with VSI of 2. From Figure 4.15, all #67 stone and manufactured sand mixtures have difference more than 2 inches which is not favorable. OPC and natural sand mixtures of VSI 1 and Fly ash mixture with VSI 2 are the only mixtures within the favorable limits of TDOT (difference is less than 2 in).

All manufactured sand mixtures showed a zero L-box ratio as shown in Figure 4.16. It is obvious that Fly ash mixtures with natural sand has a better L-box ratio that OPC mixtures. Mixtures with VSI 2 showed a better performance than VSI 1.

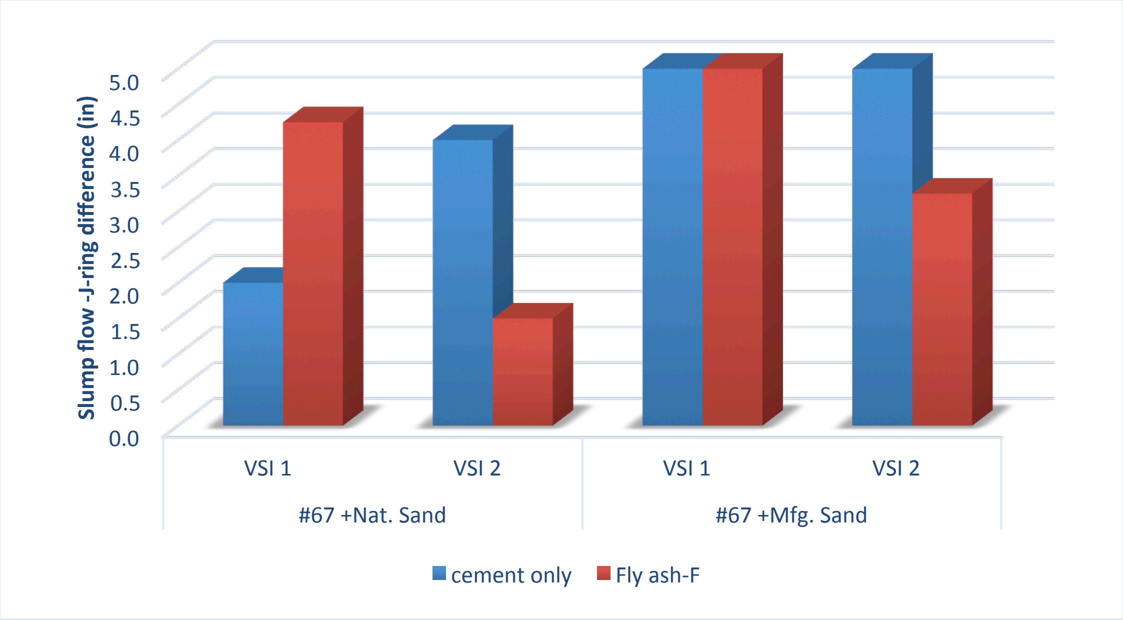


Figure 4.15 Slump Flow and J-Ring Difference for #67 Stone Mixtures

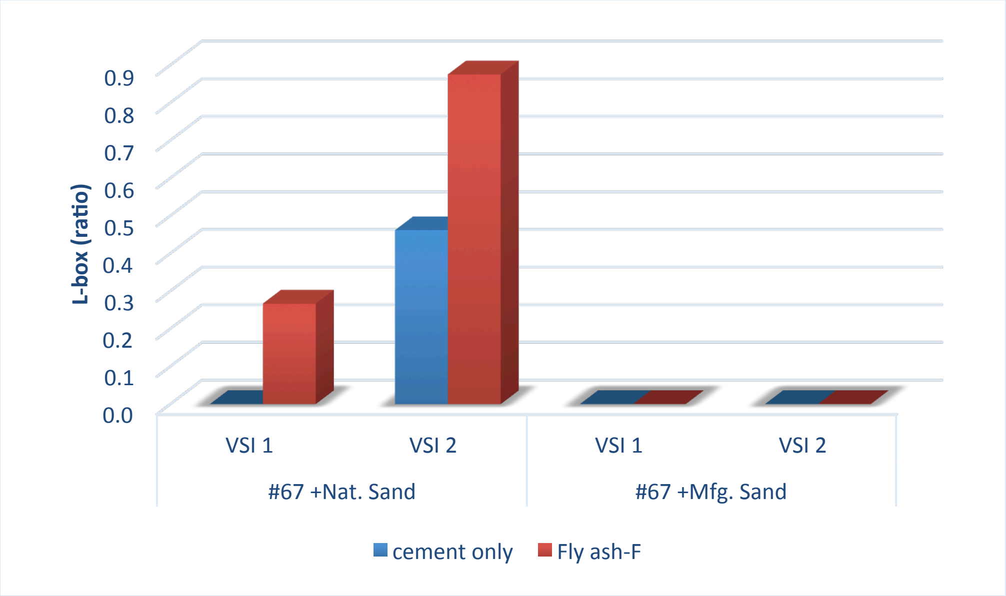


Figure 4.16 The L-Box Ratio for #67 Stone Mixtures

4.3.2.2 Mixtures Containing Coarse Aggregate #7 with Natural

As shown in Figure 4.17, the coarse aggregate #7 with VSI of 2 has a good passing ability compared to VSI of 1 mixtures. Fly ash mixtures exceled a better performance than OPC mixtures. As shown in Figure 4.18, it is obvious that Fly ash mixtures has a better L- box ratio that OPC mixtures. Mixtures with VSI 2 showed a better performance than VSI 1.

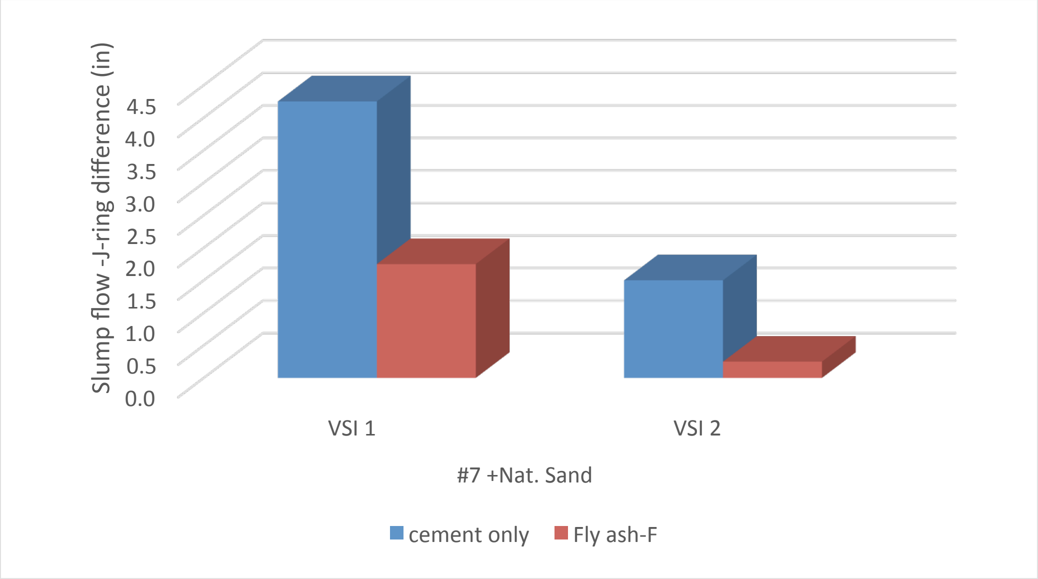


Figure 4.17 Slump Flow and J-Ring Difference for #7 Stone Mixtures

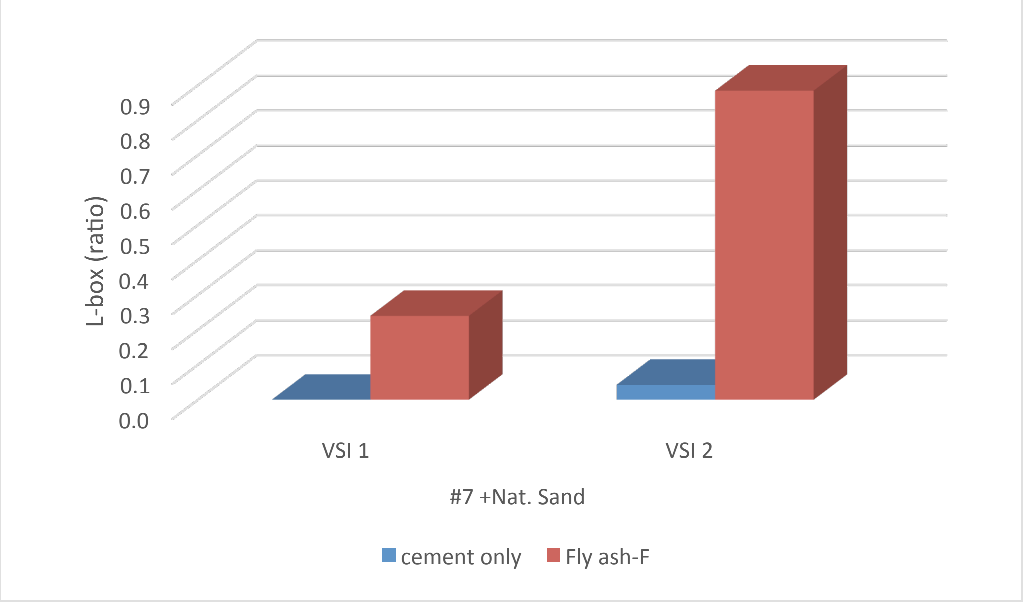


Figure 4.18 The L-Box Ratio for #7 Stone Mixtures

4.3.2.3 Mixtures Containing Coarse Aggregate #89 with Natural Sand

As shown in Figure 4.19, the coarse aggregate #7 with VSI of 2 has a good passing ability compared to VSI of 1 mixtures. Fly ash mixtures exceled a better performance than OPC mixtures. As shown in Figure 4.20, it is obvious that Fly ash mixtures has a better L- box ratio that OPC mixtures. Mixtures with VSI 2 showed a better performance than VSI 1 (L-box ratio of zero).

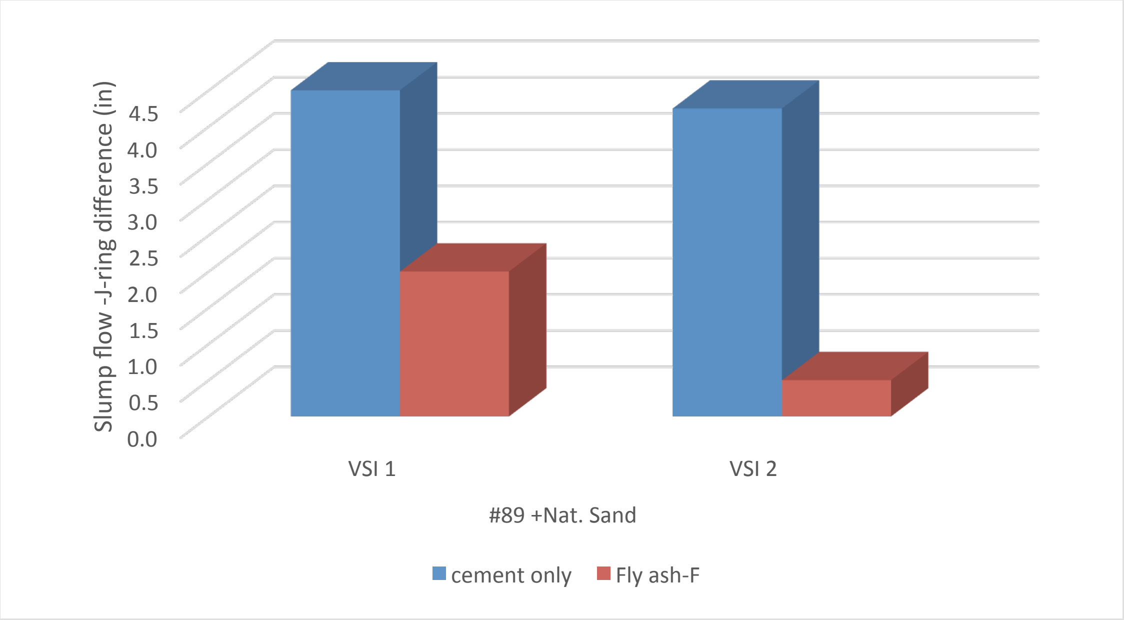


Figure 4.19 Slump flow and J-ring Difference for #89 Stone Mixtures

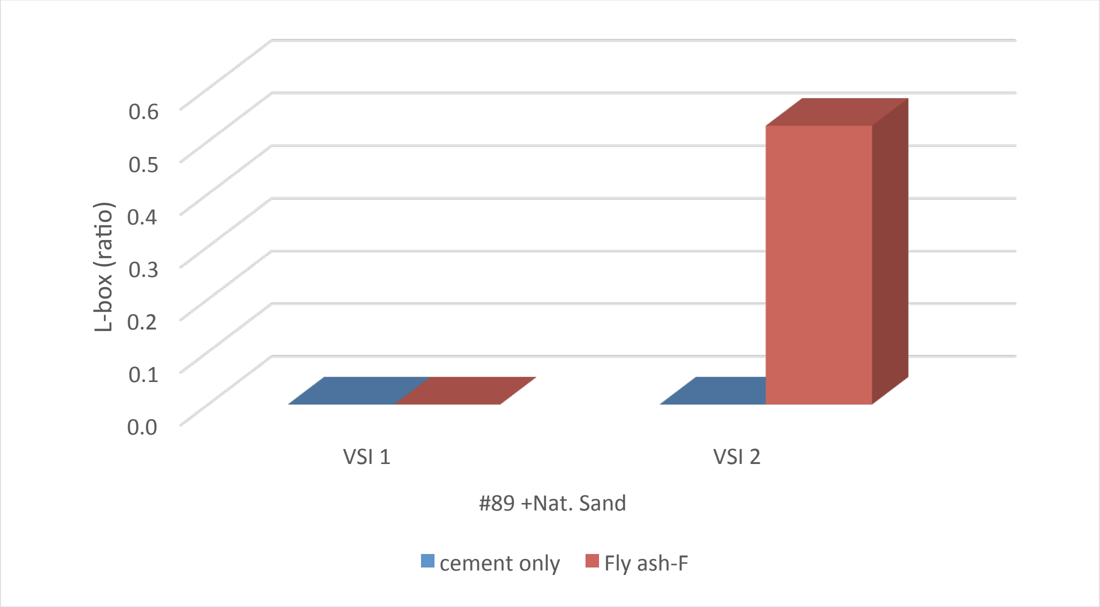


Figure 4.20 The L-Box Ratio for #89 Stone Mixtures

4.3.3 Stability of SCC Mixtures

Stability of the SCC was measured with the Column Segregation test. The acceptance limit of percent segregation recommended by ACI is less than 10% (ACI, 2007). However, some of the State DOTs specifications specify 15% as a maximum column segregation limit. The results of the Column Segregation test were obtained for different aggregate sizes as described in Section 4.2 and summarized in Figure 4.21. The stability property evaluated by column segregation ratio for each stone size are discussed separately later in this section.

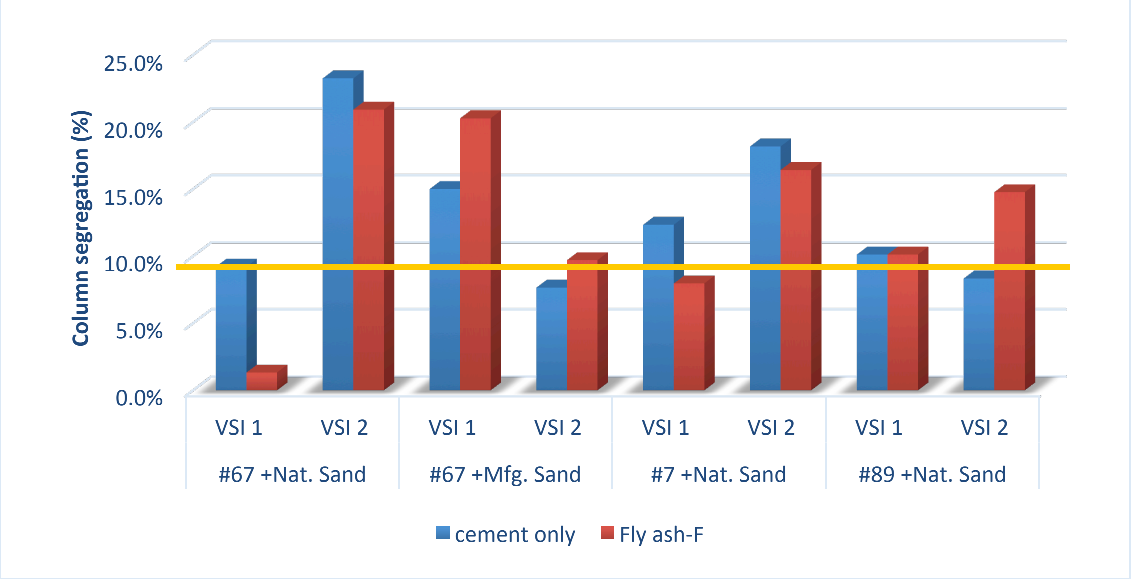


Figure 4.21 The Column Segregation for the SCC Mixtures

4.3.3.1 Mixtures Containing Coarse Aggregate #67 with Natural and Manufactured Sand

It may be noticed from Figure 4.22, the natural sand shows a less segregation potential compared to the manufactured sand with VSI of 1 and the opposite is true. Also, it can be seen clearly, Fly ash mixtures has less column segregation percentages compared to OPC mixtures when used with natural sand, and the opposite is true when using the manufactured sand. The mixtures that have segregation less than 10% were mixtures of natural sand with VSI of 1 and mixtures of manufactured sand with VSI of 2.

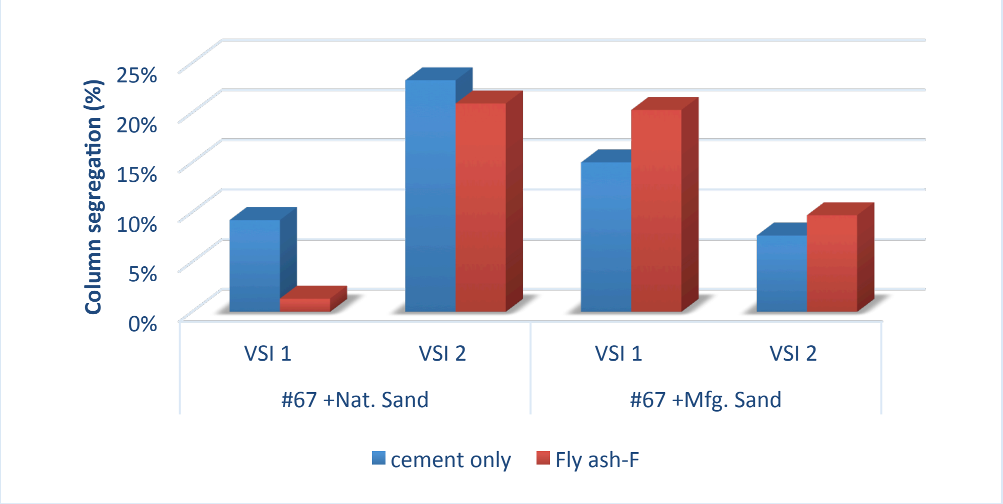


Figure 4.22 The Column Segregation for #67 Stone Mixtures

4.3.3.2 Mixtures Containing Coarse Aggregate #7 with Natural

The coarse aggregate #7 is a relatively small size aggregate. Therefore it was anticipated to show less segregation potential than #67 stone size but this was not the case. As observed from Figure 4.23, only the mixtures of fly ash and VSI of 1 has acceptable value (less than 10%). This high segregation values could be attributed to the high amount of HRWR that was added in these mixtures as shown in Figure 4.8.

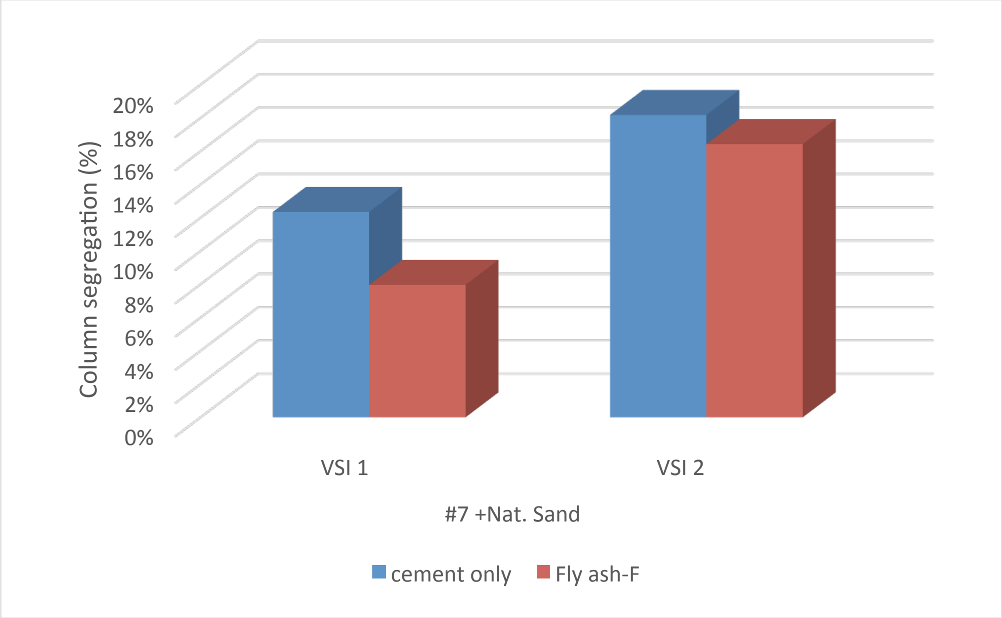


Figure 4.23 The Column Segregation for #7 Stone Mixtures

4.3.3.3 Mixtures Containing Coarse Aggregate #89 with Natural Sand

The coarse aggregate #89 was the smallest size used in this study. Studies show that the well-graded mixtures tend not to have as many problems as gap-graded mixtures in terms of workability and segregation during vibration (Richardson, 2005). As observed from Figure 4.24, all the mixtures show a relatively acceptable segregation potential except the one with the 14.35 % segregation. This high segregation value could be attributed to the high amount of HRWR that was added in this mixture as shown in Figure 4.11.

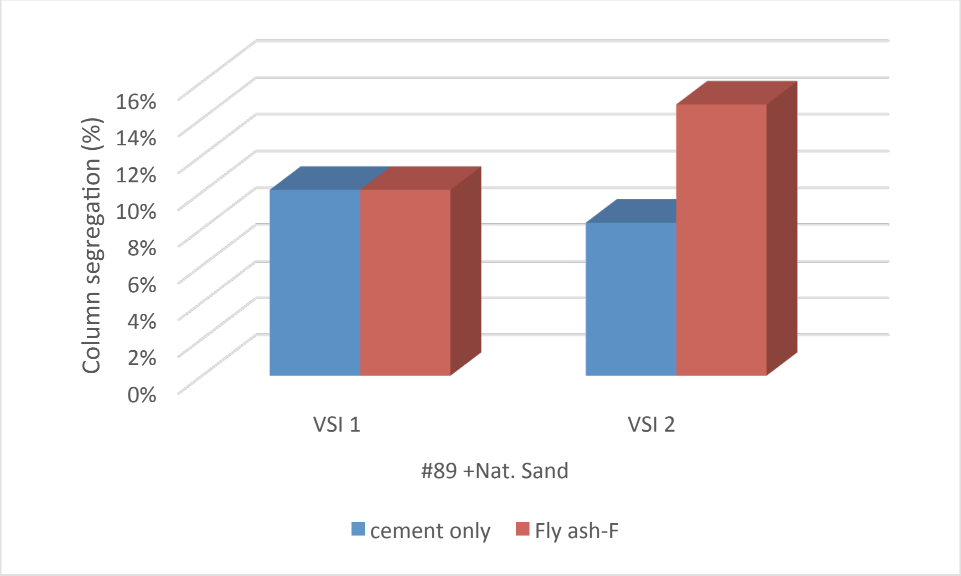


Figure 4.24 The Colum Segregation for #89 Stone Mixtures

4.3.4 Initial and Final Setting Time for SCC and Conventional Concrete Mixtures

The Time of setting of concrete mixtures was conducted for the both SCC and conventional concrete mixtures. The test used penetration resistance on a mortar sample that was obtained by sieving a representative sample of fresh concrete through sieve #4 (4.75 mm). The initial setting time is when the concrete resistance reach 500 psi, while the final setting time is when it hit the 4000 psi. The time is measured from the point cement is added to the aggregates. Conventional concrete usually has a setting time less than SCC as shown in Figure 4.25. It was not anticipated to notice much variation between the different aggregate sizes. The results of the different aggregate sizes are shown in Figure 4.25 and discussed later in details for each aggregate size.

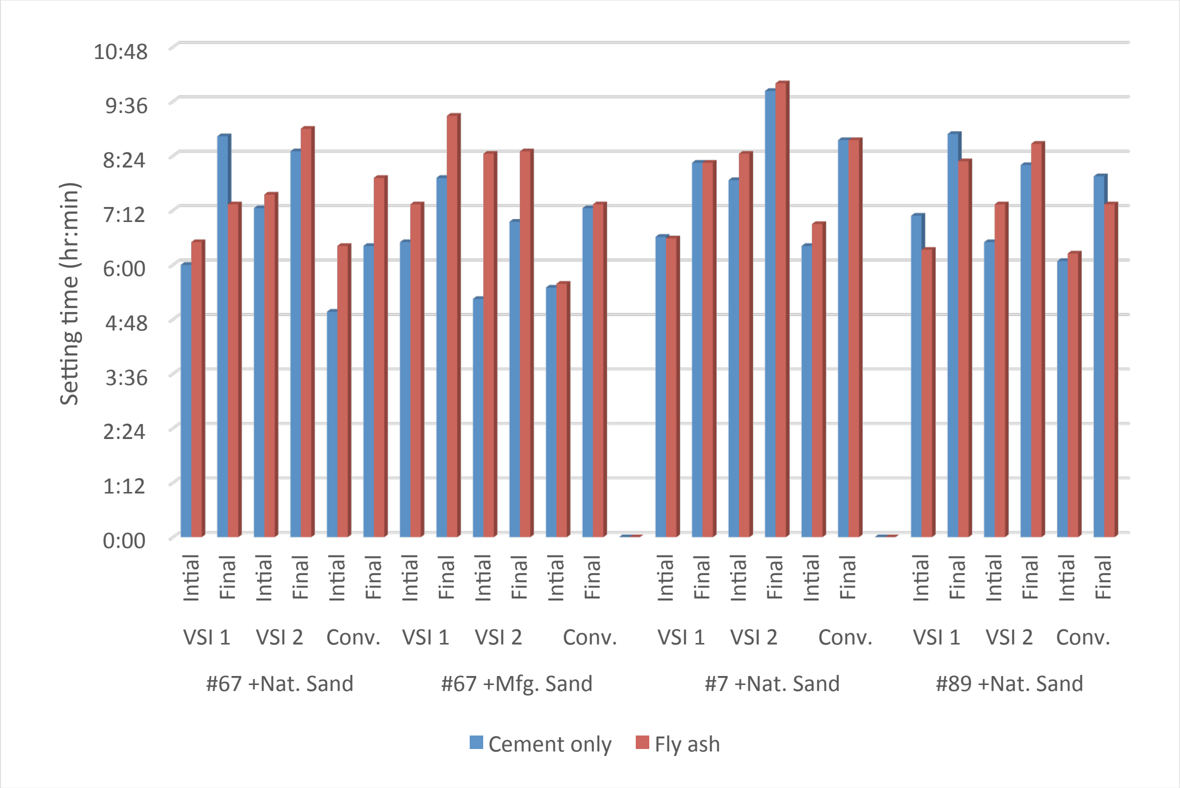


Figure 4.25 The Initial and Final Time of Setting for SCC & Conventional Mixtures

4.3.4.1 Mixtures Containing Coarse Aggregate #67 with Natural and Manufactured Sand

As shown in Figure 4.26, the manufactured sand has a faster setting time than that of the natural sand. Which could be due to the different particles gradation of the manufactured sand; which was contained larger particles than that of the natural sand. Also it can be seen, the fly ash mixtures has a longer setting time compared to the OPC mixtures. This could be attributed to the act of fly ash as a retarding agent to the concrete. Since the project concerns about early age strength shorter setting time is favorable. Also it is clear from Figure 4.26 that mixtures with VSI of 2 has a longer setting time than mixtures with VSI of 1 as a result of the higher HRWR dosages that VSI of 2 have.

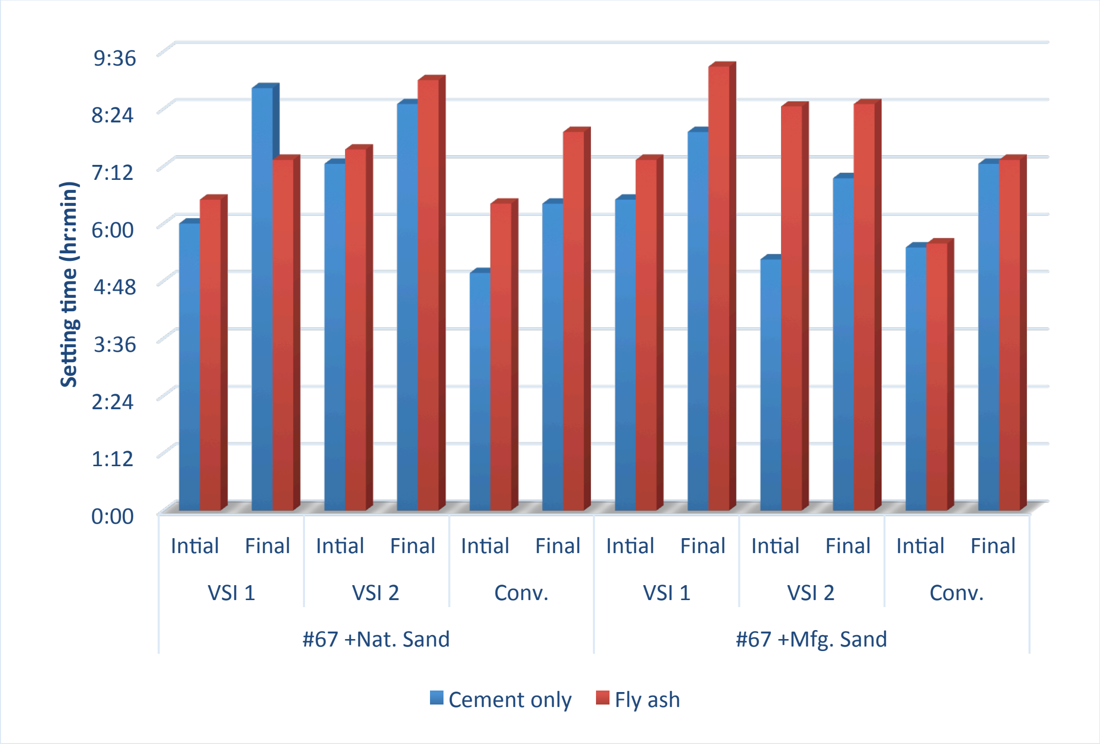


Figure 4.26 The Initial and Final Time of Setting for #67 Stone Mixtures

4.3.4.2 Mixtures Containing Coarse Aggregate #7 with Natural Sand

Figure 4.27 shows the initial and final time of setting for #7 stone, which ranged between 6 to 9.5 hours, and it was anticipated to notice such variation between the setting time between VSI of 1 and 2 and the conventional mixtures. This variation in the time of setting can be attributed to the different HRWR dosages among the mixtures; the VSI of 2 possessed the highest HRWR dosage and it showed higher time. Also that fly ash Class F is showing a slightly longer setting time than OPC mixtures.

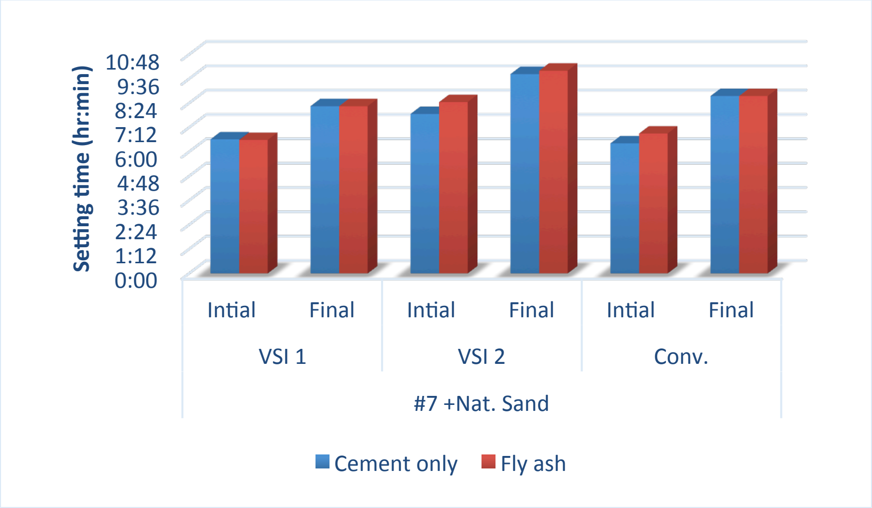


Figure 4.27 The Initial and Final Time of Setting for #7 Stone Mixtures

4.3.4.3 Mixtures Containing Coarse Aggregate #89 with Natural Sand

As shown in Figure 4.28, Fly ash mixtures of VSI 1 has shorter setting time than OPC mixtures and opposite to #67 and #7 stones mixtures. Apart from the above, the same observations that were noticed in Figures 4.26 and 4.27 could be confirmed in Figure 4.28.

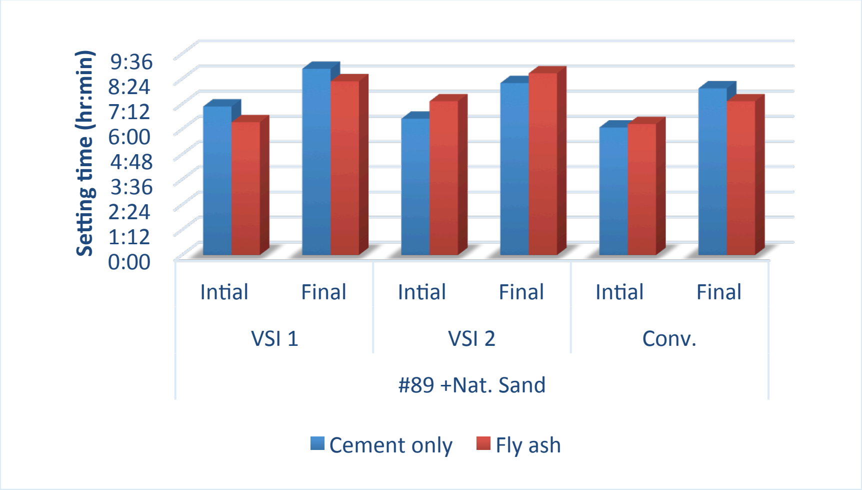


Figure 4.28 The Initial and Final Time of Setting for #89 Stone Mixtures

4.4 Discussion of Hardened Properties of Concrete Mixtures

Three tests was conducted to evaluate the hardened properties of the SCC and conventional concrete mixtures. The tests are Compressive strength, Tensile strength and Modulus of Elasticity. The tests intervals used in this study are 18 hours tests and 28 days tests results. TDOT requires 18 hours compressive strength to be not less than 4000 psi. The hardened properties tests are discussed with correlate to aggregates sizes in details in the following section.

4.4.1 The Compressive Strength for the Studied Mixtures

The compressive strength results that shown in Table 4.2 are summarized in Figure 4.29 which is 18 hours results and Figure 4.30 which is 28 days results.

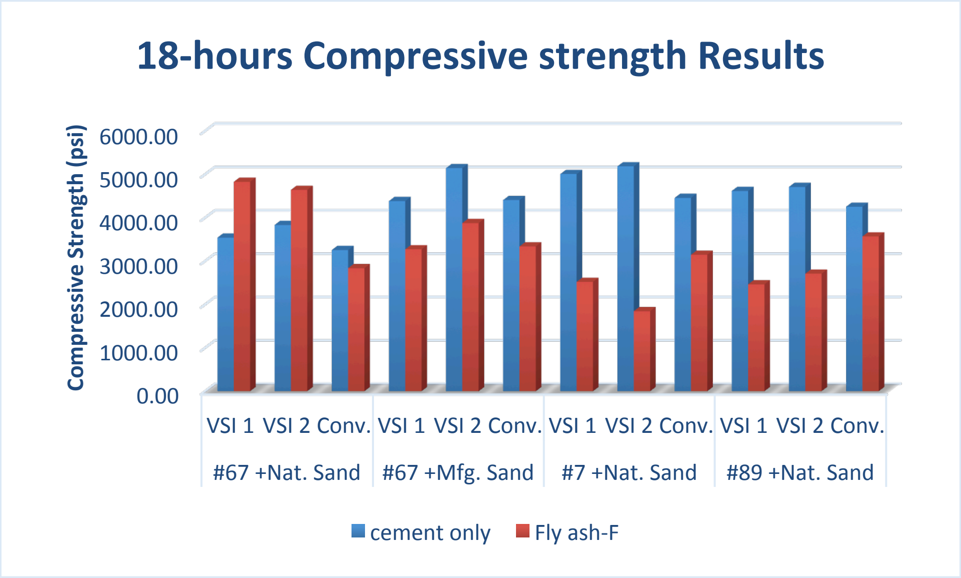


Figure 4.29 The 18-hours Compressive Strength of the Studied Mixtures

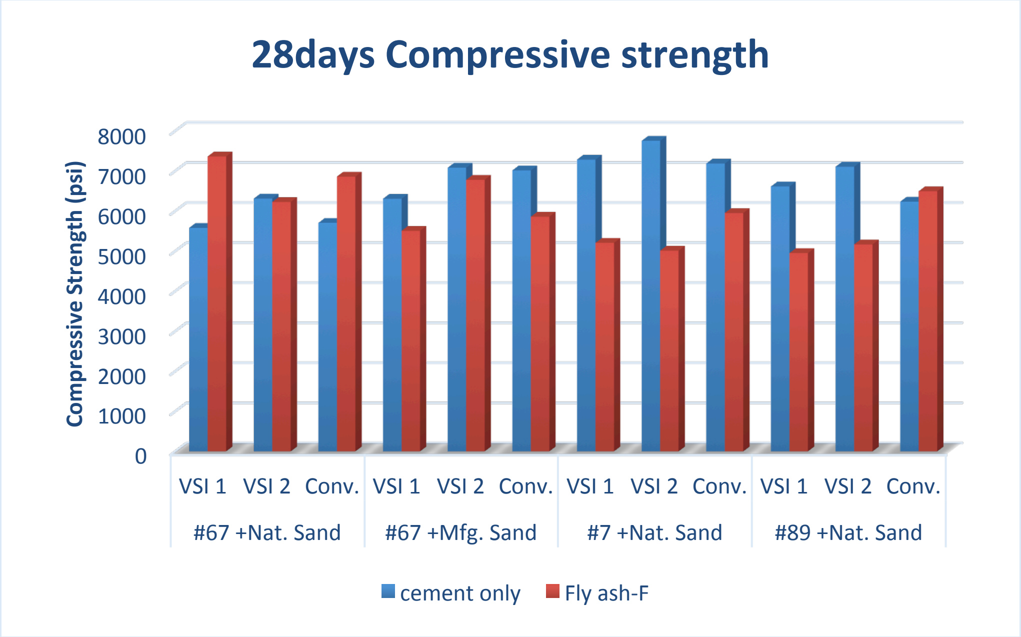


Figure 4.30 The 28 Days Compressive Strength of the Studied Mixtures

4.4.1.1 Mixtures Containing Coarse Aggregates #67 with Natural and Manufactured Sand

As shown in Figure 4.31 that manufactured sand mixtures has an early age compressive strength above 4000 psi when mixed with OPC and lower than 4000 psi when mixed with fly ash. Natural sand mixtures has the opposite behavior of the manufactured sand. Natural sand mixture with OPC has a higher compressive strength when using VSI of 1 than VSI of 2. It's clear that in case of Class-P Concrete it's better to use manufactured sand with statement or use natural sand with fly ash. All the mixtures showed a good compressive strength after 28 days as shown in Figure 4.32.

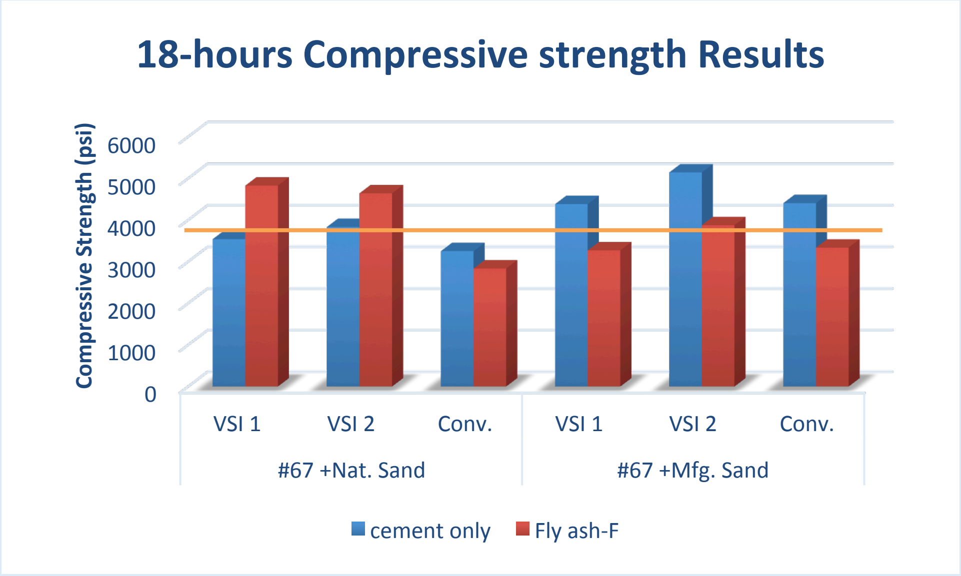


Figure 4.31 The 18-hours Compressive Strength of #67 Stone Mixtures

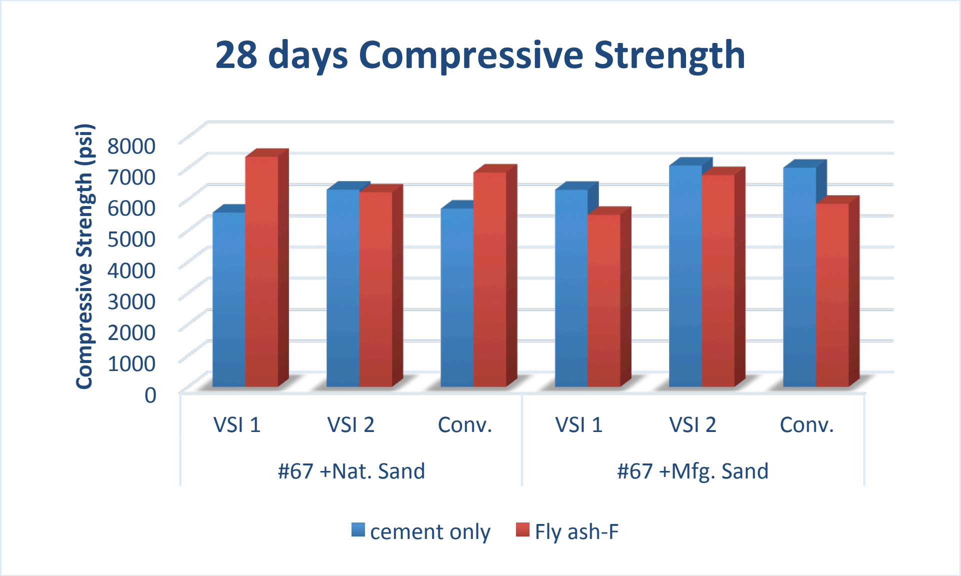


Figure 4.32 The 28 Days Compressive Strength of #67 Stone Mixtures

4.4.1.2 Mixtures Containing Coarse Aggregates #7 with Natural Sand

As shown in Figure 4.33, that OPC mixtures has an early age compressive strength above 4000 psi, while fly ash mixtures has a compressive strength way less than 4000 psi. This phenomena could be attributed to the fly ash slow reaction compared to the cement. Also it was not the case with #67 stone because #7 stone has a smaller size aggregates which means more surface area needed for the reaction of the Cementious materials and the evidence to this is the high setting time needed #7 stone mixtures with fly ash compared to their OPC mixtures as shown in Figure 4.27. With the above mentioned reasons, it makes harder to achieve a higher early age strength. The same results happened with 28 days results as shown in Figure 4.34.

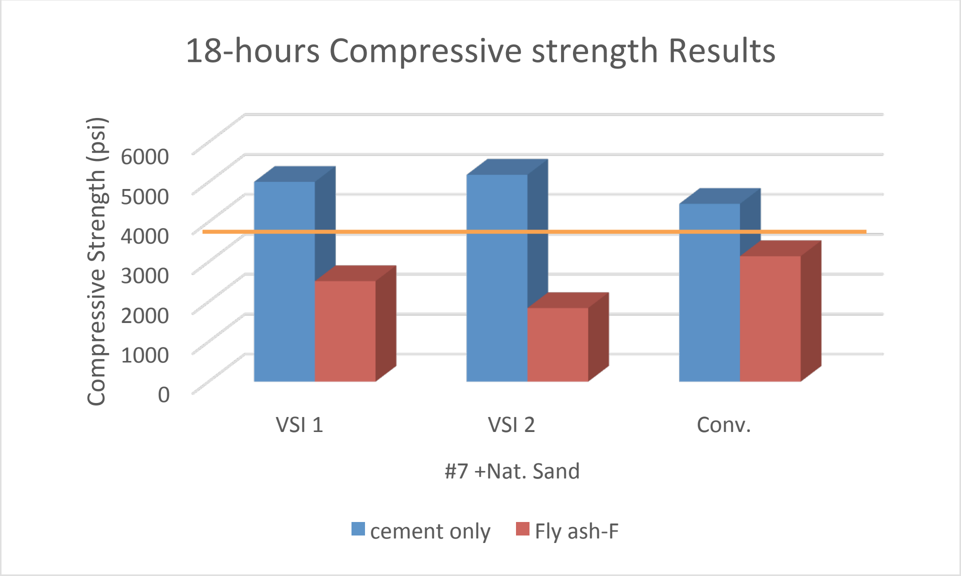


Figure 4.33 The 18-hours Compressive Strength of #7 Stone Mixtures

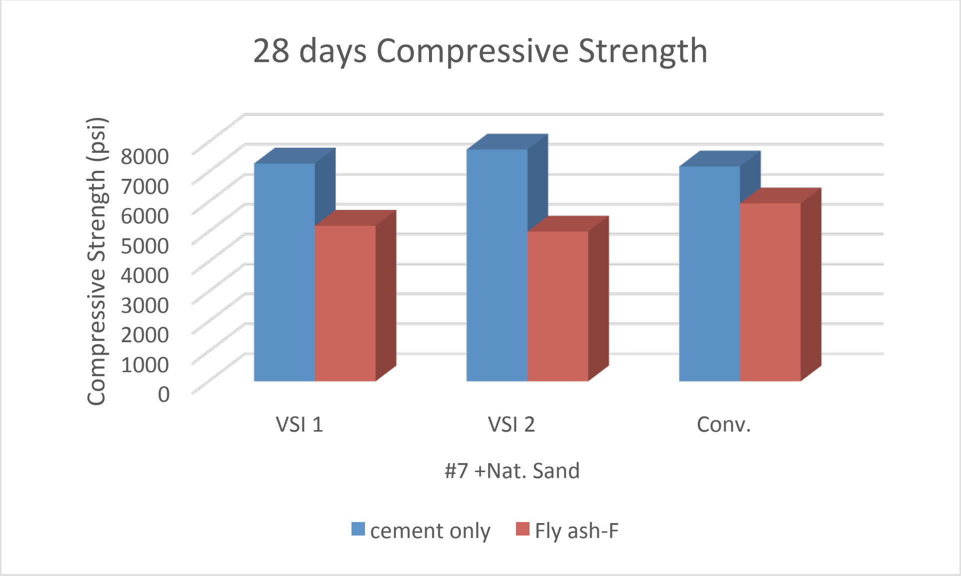


Figure 4.34 The 28 Days Compressive Strength of #7 Stone Mixtures

4.4.1.3 Mixtures Containing Coarse Aggregates #89 with Natural Sand

As shown in Figure 4.35, exact the same as stone #7 that OPC mixtures has a compressive strength above 4000 psi, while fly ash mixtures has a compressive strength less than 4000 psi. This phenomena could be attributed to the fly ash slow reaction compared to the cement. Since #7 stone and #89 stone has smaller size aggregates that means more surface area needed for the reaction of the Cementious materials and more time, and the evidence to this is the high setting time needed for both #7 and #89 stone mixtures with fly ash compared to their OPC mixtures as shown in Figure 4.27 and Figure 4.28. With the above mentioned reasons, it makes harder to achieve a higher early age strength when using fly ash with smaller size aggregates. The same results happened with 28 days results as shown in Figure 4.36.

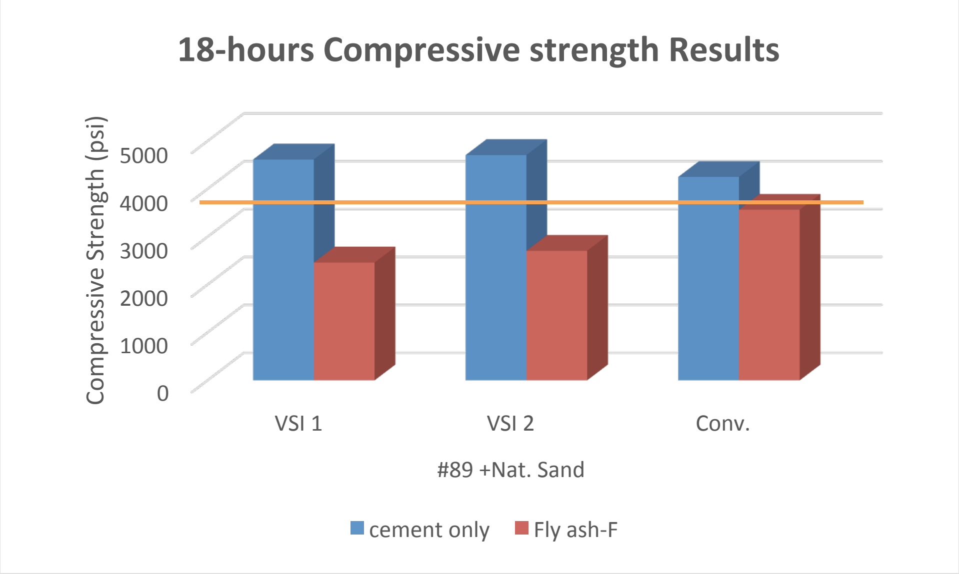


Figure 4.35 The 18-hours Compressive Strength of #89 Stone Mixtures

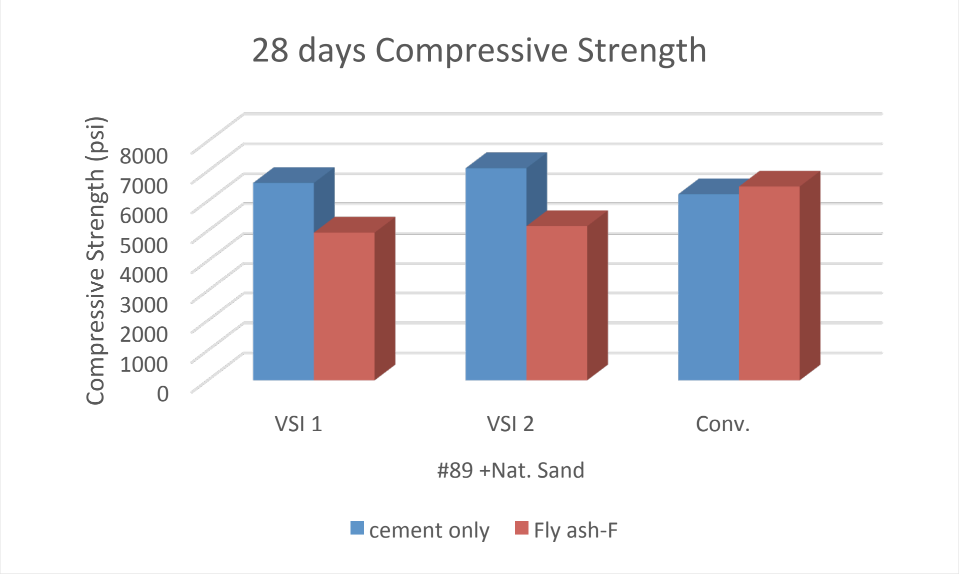


Figure 4.36 The 28 Days Compressive Strength of #89 Stone Mixtures

4.4.2 The Tensile Strength of the Studied Mixtures

The modulus of elasticity test was performed for all SCC and conventional mixtures. The results of the test shown in Table 4.2 and summarized in Figures 4.37 for 18-hours results and Figure 4.38 for 28 days. Each aggregate size results is discussed in detail in this section.

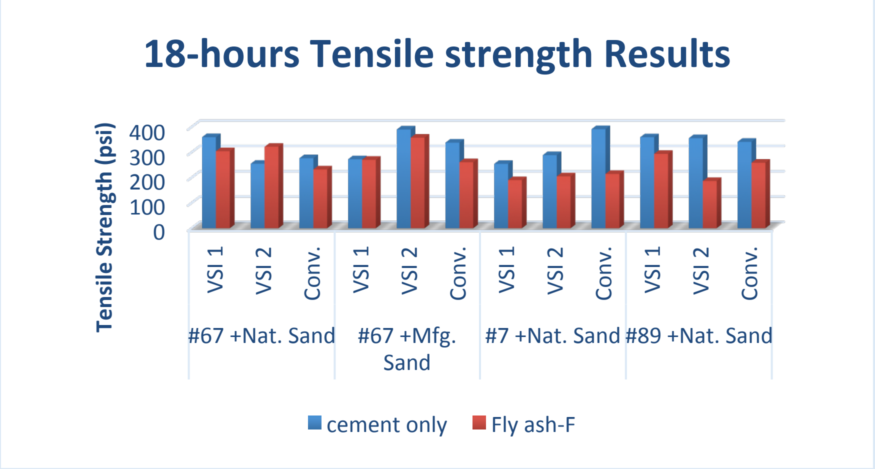


Figure 4.37 The 18-hours Tensile Strength Results for the Studied Mixtures

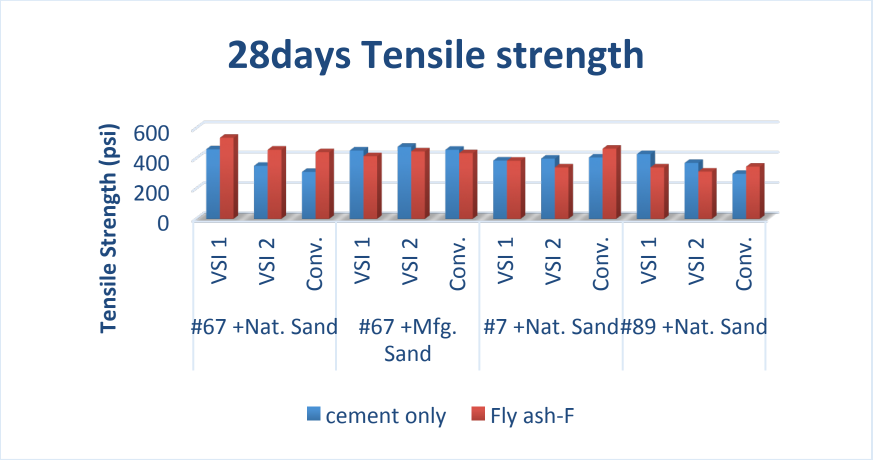


Figure 4.38 The 28 Days Tensile Strength Results for the Studied Mixtures

4.4.2.1 Mixtures Containing Coarse Aggregates #67 with Natural and Manufactured Sand

As shown in Figure 4.39, that fly ash with natural sand mixture showed a slightly higher 18 hours tensile strength than OPC mixture with VSI of 2, but apart from that OPC mixtures have a relatively higher tensile strength values than fly ash mixtures for SCC and conventional mixtures. While for the 28 days tests fly ash mixtures have higher tensile strength than OPC mixtures when using natural sand and lower strength with manufactured sand as shown in Figure 4.40. This could be attributed to the slower reaction of the fly ash in the early age of the concrete.

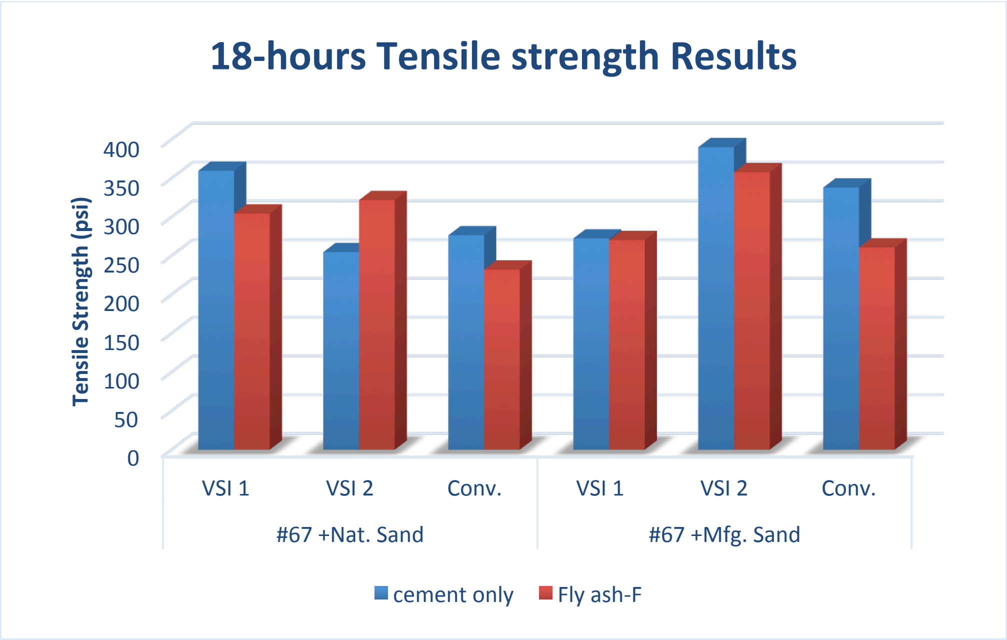


Figure 4.39 The 18-hours Tensile Strength of #67 Stone Mixtures

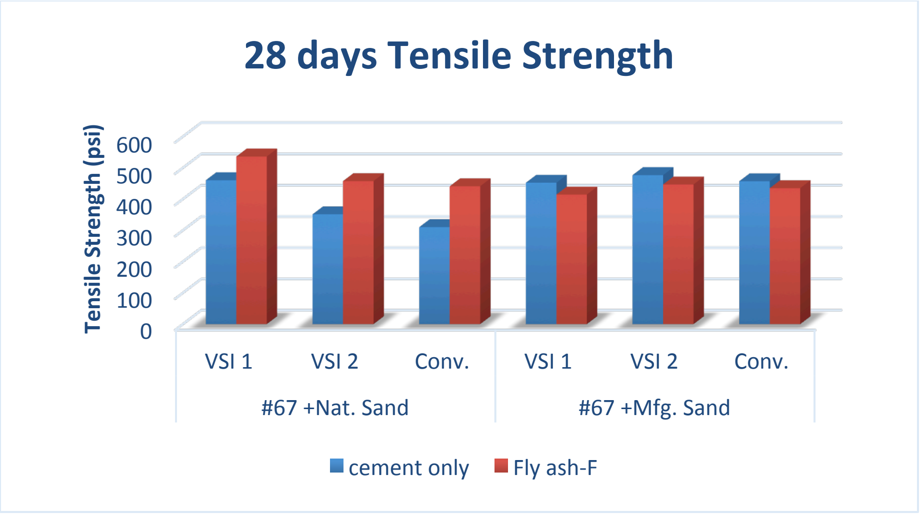


Figure 4.40 The 28 Days Tensile Strength of #67 Stone Mixtures

4.4.2.2 Mixtures Containing Coarse Aggregates #7 with Natural Sand

As shown in Figure 4.41, that OPC mixtures have higher early age tensile strength than fly ash mixtures, while the values are very much equal in 28 days as shown in Figure 4.42. This could be attributed to the slower reaction of the fly ash in the early age of the concrete.

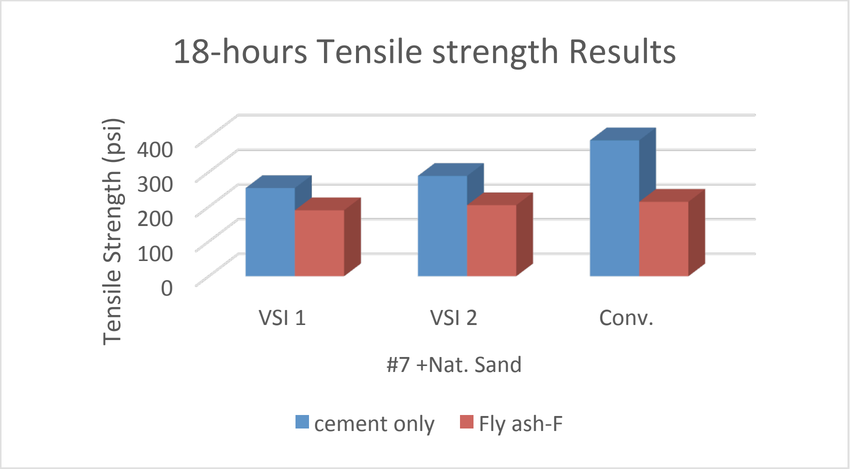


Figure 4.41 The 18-hours Tensile Strength of #7 Stone Mixtures

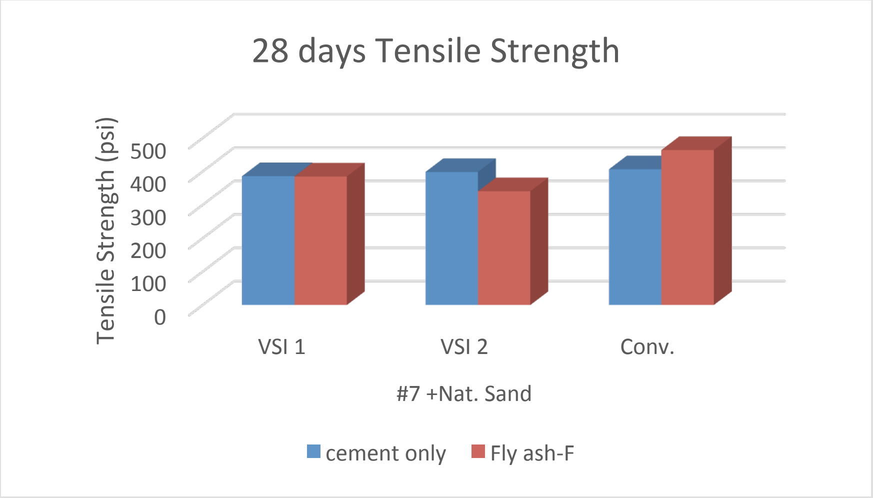


Figure 4.42 The 28 Days Tensile Strength of #7 Stone Mixtures

4.4.2.3 Mixtures Containing Coarse Aggregates #89 with Natural Sand

As shown in Figure 4.43, and the same as #7 stone mixtures that OPC mixtures have higher early age tensile strength than fly ash mixtures, while the values are close in 28 days as shown in Figure 4.44. This could be attributed to the slower reaction of the fly ash in the early age of the concrete.

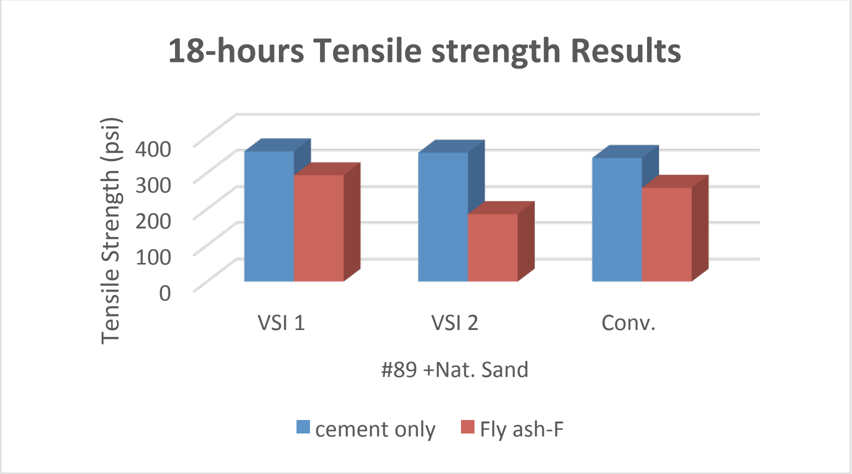


Figure 4.43 The 18-hours Tensile Strength of #89 Stone Mixtures

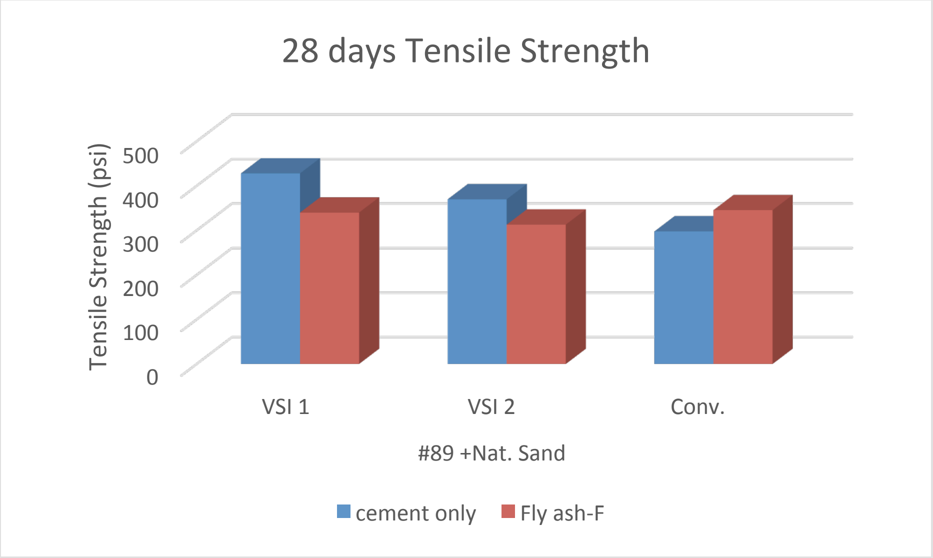


Figure 4.44 The 28 Days Tensile Strength of #89 Stone Mixtures

4.4.3 Modulus Elasticity of the Studied Mixtures

The Modulus of Elasticity test was performed on the studied mixtures as described in chapter 2. The results of the test are shown in Table 4.2 and summarized in Figure 4.45 for the 18 hours tests and Figure 4.46 for the 28 days tests. Each aggregate size results is discussed in detail in this section.

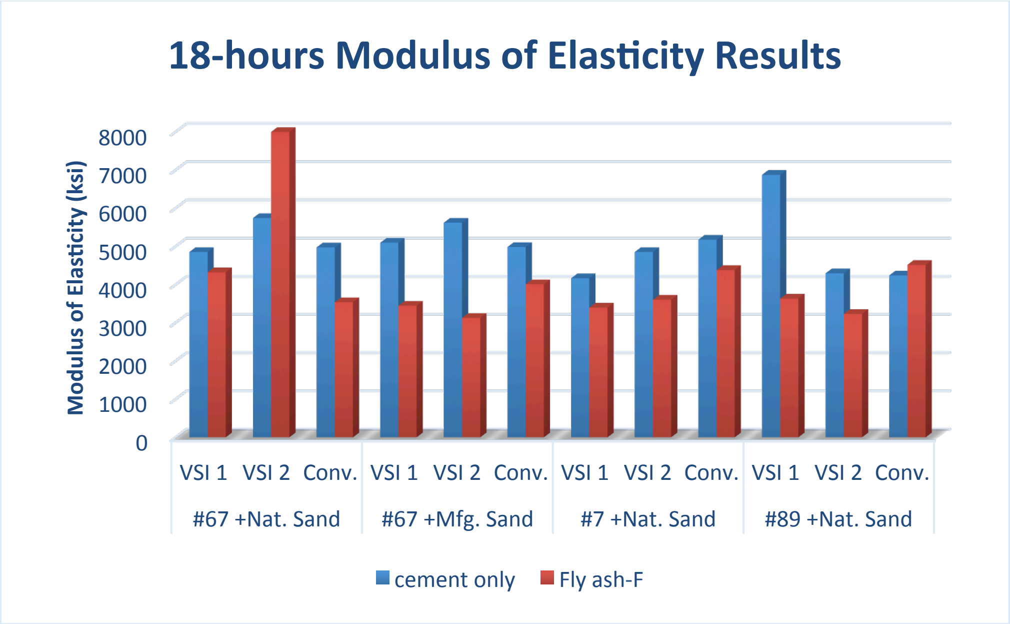


Figure 4.45 The 18-hours Modulus of Elasticity Results for the Studied Mixtures

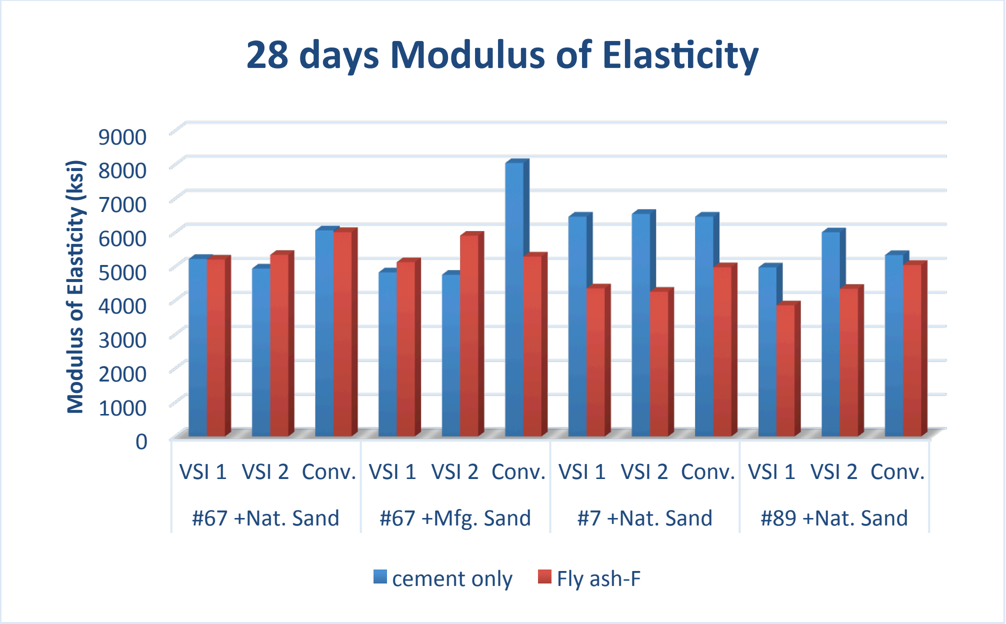


Figure 4.46 The 28 Days Modulus of Elasticity Results for the Studied Mixtures

4.4.3.1 Mixtures Containing Coarse Aggregates #67 with Natural and Manufactured Sand

As shown in Figure 4.47 that the early age modulus of elasticity is slightly higher in OPC mixtures than fly ash mixtures, except for VSI of 2 of natural sand. While after 28 days, it is clear that all natural sand mixtures with fly ash have more modulus of elasticity than OPC mixtures when mixed with natural sand and the opposite is true for manufactured sand as shown in Figure 4.48. This could be attributed to the slower reaction of the fly ash in the early age of the concrete.

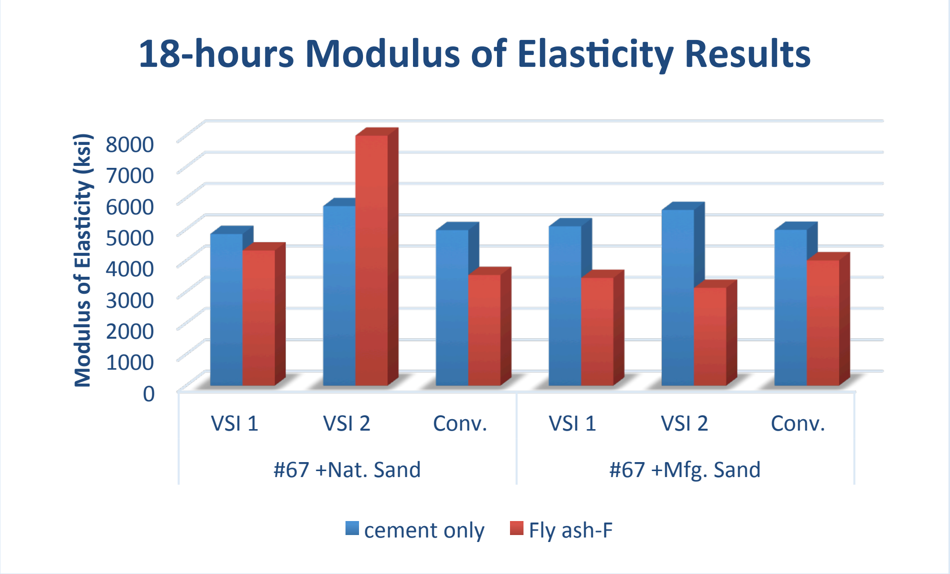


Figure 4.47 The 18-hours Modulus of Elasticity for #67 Stone Mixtures

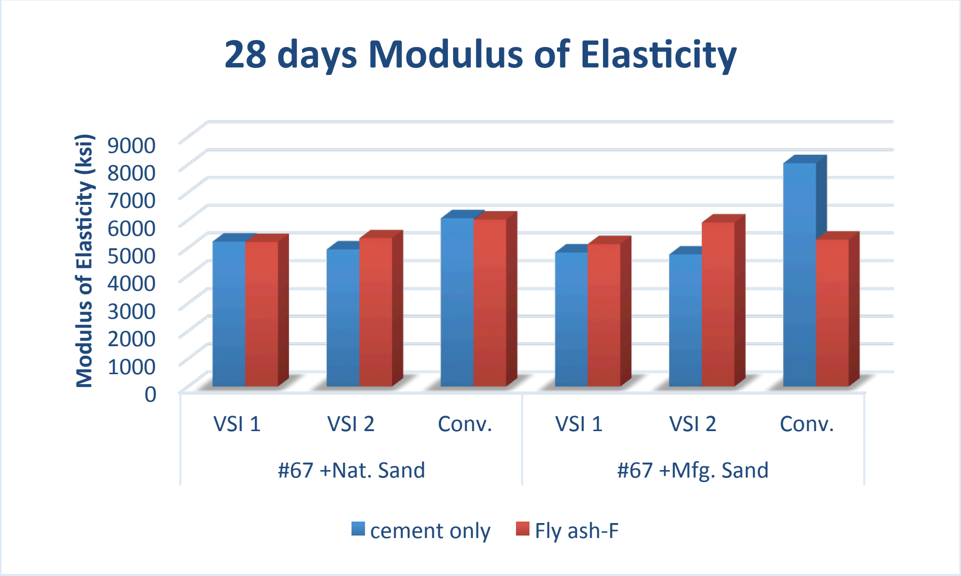


Figure 4.48 The 28 Days Modulus of Elasticity for #67 Stone Mixtures

4.4.3.2 Mixtures Containing Coarse Aggregates #7 with Natural Sand

As shown in Figure 4.49 that #7 stone mixtures have a higher early age modulus of elasticity when mixed only with OPC than fly ash mixtures, but the fly ash mixtures gained more at 28 days as shown in Figure 4.50 and it’s even has a higher value in the conventional concrete case. This could be attributed to the slower reaction of the fly ash in the early age of the concrete.

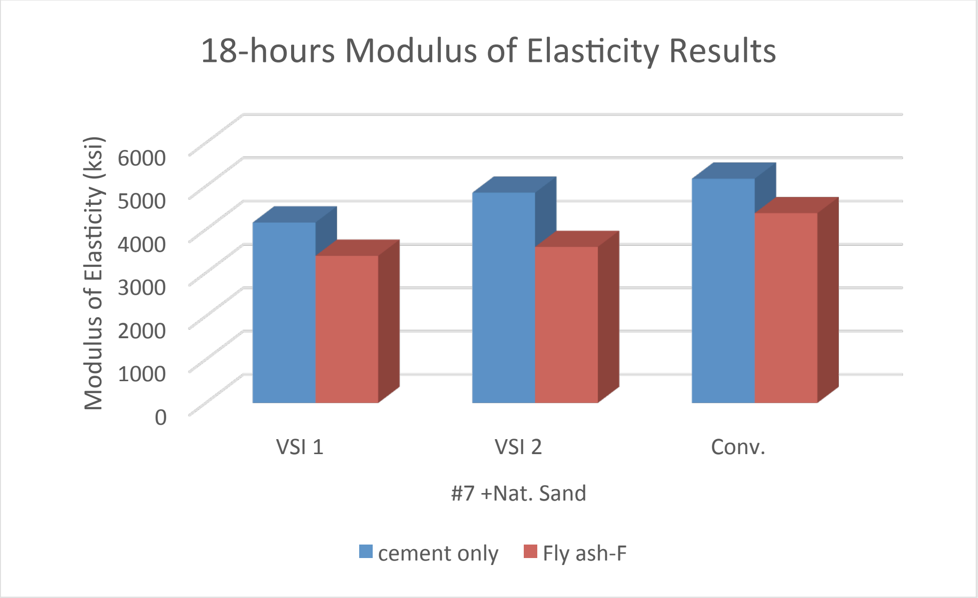


Figure 4.49 The 18-hours Modulus of Elasticity for #7 Stone Mixtures

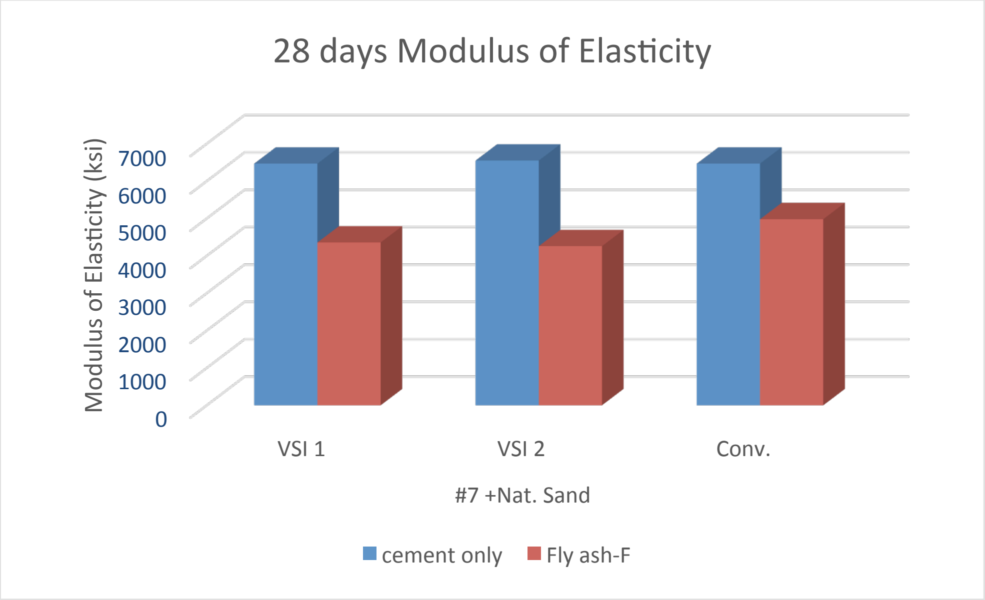


Figure 4.50 The 28 Days Modulus of Elasticity for #7 Stone Mixtures

4.4.3.3 Mixtures Containing Coarse Aggregates #89 with Natural Sand

The same observations could be seen in #89 stone mixtures as #7 mixtures from Figure 4.51 and Figure 4.52.

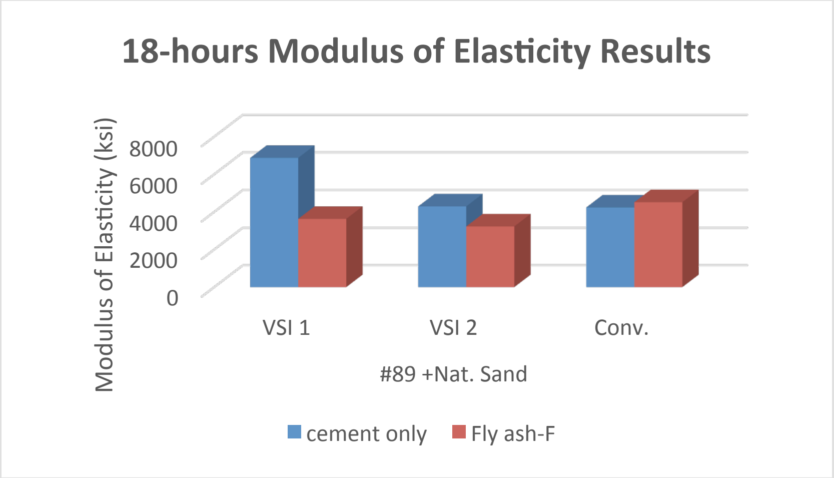


Figure 4.51 The 18-hours Modulus of Elasticity for #89 Stone Mixtures

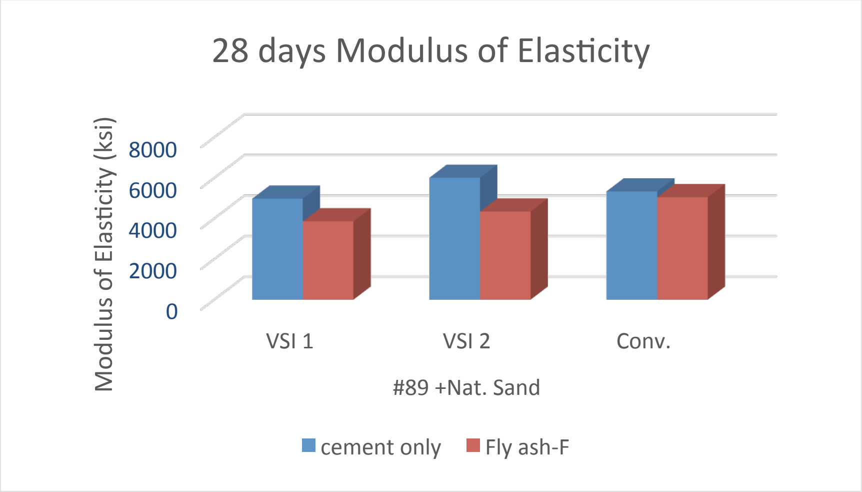


Figure 4.52 The 28 Days Modulus of Elasticity for #89 Stone Mixtures

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Observations and Conclusions

5.1.1 Observations and Conclusions from #67 Stone Concrete Mixtures

- The natural sand mixtures has a better filling and passing ability for #67 stone mixtures than that of the manufactured sand. The manufactured sand possesses poor passing ability.
- Manufactured sand showed a high segregation potential with VSI of 1 mixtures, while natural sand mixtures has a high segregation potential with VSI of 2.
- The mixtures containing natural sand show lower relative viscosity and longer setting times than the mixtures containing manufactured sand.
- The results indicated that manufactured sand mixtures have higher compressive strength than natural sand mixtures when combined with OPC only.
- Using Class F fly ash improves the compressive strength of #67 stone mixtures mixed with natural sand (compressive strength more than 4000 psi) and lower the compressive strength when mixed with manufactured sand
- Generally, #67 stone mixtures show better fresh properties with natural sand than manufactured sand, and better hardened properties when mixed with fly ash.

Manufactured sand mixtures only showed a better hardened properties with OPC mixtures.

5.1.2 Observations and Conclusions from #7 Stone Concrete Mixtures

- In general, the #7 stone mixtures have better fresh properties than #67 stone mixtures. And have good hardened properties when combined with OPC only.
- The test results indicated that Class F fly ash mixtures have poor hardened properties (compressive strength less than 4000 psi), also fly ash mixtures has more setting time than OPC mixtures this could be attributed to the slow reaction process of the fly ash.
- The coarse aggregate #7 mixtures are more convenient for making Class-P SCC mixtures when cement was used as the sole cementious materials.

5.1.3 Observations and Conclusions from #89 Stone Concrete Mixtures

- The #89 stone mixtures have better fresh properties than #67 stone mixtures have. In addition they have good hardened properties when mixed with OPC only.
- The test results indicated that the Class F fly ash mixtures has a poor hardened properties, this could be attributed to the slow reaction process of the fly ash
- The coarse aggregate #89 mixtures are more convenient for making Class-P SCC mixtures when only cement was used as the sole cementious materials.

5.2 Recommendations

- The results of this study have indicated that Class- P SCC mixtures made with #67 stone has a good results only when mixed with Class-F fly ash and natural sand and when producing VSI of 1.
- The combination of #67 stone and manufactured sand is not recommended, because it shows high segregation potential and low passing ability.
- The #7 and #89 aggregates with OPC are highly recommended in order to produce Class-P SCC mixtures with high flowability, high passing ability, and with less segregation potential and a good early age compressive strength.
- The test results indicated that using Class F fly ash is only recommended with large size aggregates like #67.
- It is also recommended for future work to investigate the use a blended fine aggregate of natural and manufactured sand and study their effect on the fresh characteristics of SCC. Also investigate the effect of using manufactured sand with smaller size aggregates like #7 and #89 stone sizes on the early age compressive strength.

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VITA

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