Report No. BD 503

MIX DESIGN AND TESTING OF SELF-CONSOLIDATING CONCRETE USING FLORIDA MATERIALS

Final Report Submitted to

The Florida Department of Transportation

(Contract No. BD 503)

By

Ashok H. Gurjar, Ph.D., P.E.

Associate Professor

Department of Civil Engineering

Embry-Riddle Aeronautical University

Daytona Beach, FL 32114

December 2004

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle **Mix Design And Testing Of Self-Consolidating Concrete Using Florida Materials**		5. Report Date 6. Performing Organization Code
7. Author(s) **Ashok H. Gurjar**		8. Performing Organization Report No.
9. Performing Organization Name and Address **Embry-Riddle Aeronautical University** **Dept. of Civil Engineering** **600 S Clyde Morris Blvd, Daytona Beach, FL 32114**		10. Work Unit No. (TRAIS) 11. Contract or Grant No. **BD-503**
12. Sponsoring Agency Name and Address **Florida Department of Transportation** **605 Suwannee St. MS 30** **Tallahassee, Florida 32399** **(850)414-4615**		13. Type of Report and Period Covered **Final Report** 14. Sponsoring Agency Code
15. Supplementary Notes **Prepared in cooperation with the FDOT**		

16. Abstract

Self-consolidating concrete (SCC) is a highly flowable, yet stable concrete that can spread readily into place and fill the formwork without any consolidation and without undergoing any significant separation. In general, SCC result in reduced construction times and reduced noise pollution. SCC has been produced using high powder content, using viscosity modifying agents or combination of the two. Investigation of flow characteristics and fresh concrete properties of SCC and the effect of sand to total aggregate ratio, fly ash, silica fume, slag, cement content and w/cm ratio were carried out. Additionally, economic impact issues were addressed and guidelines were proposed. Based on findings, it is also recommended that a minimum cementitious content of 825 lb/yd^3 should be used for w/cm ratio below 0.37 and a minimum of 900 lb/yd^3 for w/cm below 0.33. It was found that the rheological tests such as slump flow, L-box, U-box and V-funnel although not standardized yet are sufficient to ascertain SCC attributes. Stability and segregation resistance of SCC mixes needs further study and development and VSI rating may not be enough to distinguish a segregating concrete. VSI is subjective and hence prone to error. There was no statistical difference found in performing slump-flow test using inverted cone or upright cone. Silica fume and slag were found to be viable secondary cementitious material in SCC. Based on the study carried out, it is suggested that no more than 6% silica and no more than 40% slag be replaced by mass in SCC. In addition, it is also suggested that a minimum of 10% fly ash be recommended with slag usage. Because the technology for making self-consolidating concrete is mostly in the hands of the ready-mix producer and because of local variations in properties of available materials, the best approach is to use a performance-based specification instead of specifying the specifics of the mix design. The economic impact of switching to using SCC should be analyzed at the plant. Trial batches should be performed in close relationship with the admixture supplier to identify the exact combination of admixtures and other concreting materials needed to optimize the element, in terms of both engineering performance and cost efficiency. It is well documented that the increase in raw material costs are easily offset with improvements in pouring productivity and reductions in vibrator cost and maintenance.

17. Key Word	18. Distribution Statement
Self-Consolidating Concrete, Self-Compacting Concrete, Mix proportioning, Fresh Concrete Properties, Guidelines, Flowability, Slump flow, L-Box, U-Box, V-funnel, VMA	**No Restriction** **This report is available to the public through the NTIS, Springfield, VA 22161**

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	**Unclassified**		

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOGRAPHS

CHAPTER 1

INTRODUCTION

1.1 Definition of Self Consolidating Concrete (SCC)

Placement of concrete generally requires consolidation by vibration in the forms. Self-Consolidating concrete (SCC) has been defined as "a highly flowable, yet stable concrete that can spread readily into place and fill the formwork without any consolidation and without undergoing any significant separation", (Khayat, Hu and Monty, Proceeding First International RILEM Symposium, SCC, Stockholm 1999). An alternative specification suggest SCC as "a flowing concrete without segregation and bleeding, capable of filling spaces and dense reinforcement or inaccessible voids without hindrance or blockage"

The composition of SCC must be designed in order not to separate, e.g. to create excessive bleedwater and settle out the coarse fraction (sedimentation). Air entrainment is also possible for SCC to increase the concrete's resistance to frost or frost thawing salts.

The use of SCC in the actual structure has steadily increased in the recent years and presents an excellent alternative to conventional concrete for high-density or intricate reinforced sections and placement in narrow molds. SCC can also be pumped from the bottom of a form or dropped from the top with a recommended maximum fall height of 6 feet.

In general, SCC provides following advantages over conventional concrete:

- Simple placement in complicated formwork and tight reinforcement

- Reduced construction times, especially at large construction sites (due to no compaction work)
- Reduced noise pollution (since vibrators are not necessary)
- Higher and more homogenous concrete quality across the entire concrete cross-section, especially around the reinforcement
- Concreting deep elements in single lifts
- Improved concrete surfaces and finishes
- Typically higher early strength of the concrete (formwork can be removed quickly)
- Higher moisture retention may aid curing

With these stated advantages, SCC usage is on the rise worldwide for cast in-place and particularly for precast concrete construction. Many agencies worldwide have shown interest and are working towards developing tests, specification and finally adopting this type of concrete. Lot of initial work and investigation have been done in Japan and Europe and it is important to develop the knowledge, understanding and the usage of SCC in the United States for its adoption and enhancement of the concrete products.

1.2 Requirements For Self-Consolidating Concrete

SCC must possess following three characteristics to meet its stated workability requirements:

1. Filling ability: The ability of SCC to flow into and fill completely all spaces within the formwork under its own weight.
2. Passing ability: The ability of SCC to flow through tight openings such as between reinforcing rebars without segregation or blocking
3. Segregation resistance: The ability of SCC to remain homogeneous during transportation and placing.

For the concrete to possess adequate filling ability, the interparticle friction of the materials must be reduced. This can be achieved by reducing the surface tension and optimizing the packing of fine particles. Resistance to segregation can be improved by minimizing the free water to avoid bleeding and by making the liquid phase more viscous to enhance suspension of particles. Viscosity modifying agents (VMA) and/or higher fine content have been used to accomplish higher viscosity. In addition to the above workability requirements, the concrete must also possess adequate strength, durability and bleeding resistance.

1.3 Test Methods to Measure Fresh SCC Properties

At present, there are no standard ASTM or AASHTO procedures or standard test methods available to characterize the properties of SCC. ASTM Committee C09 on Concrete and Concrete Aggregates met with various constituencies such as concrete producers, engineers, transportation officials, manufactures etc. during ASTM summer 2001 meeting in Norfolk, Va. to discuss SCC admixture standards. A subcommittee (C09.47) was created to review specific standard requirements for such mix agents, and scope for a basic standard.

Following is a brief discussion on the methods employed to measure the fresh and hardened concrete properties. For the SCC tests, the current conventional tests methods are employed with exception of compaction requirement during specimen preparations. For tests such as air content measurement, compressive strength sampling, rapid chloride penetration test sample preparation no tamping or vibration will be used.

1.3.1 Workability (Rheology) Tests

There is no single test that can adequately measure the three workability requirements mentioned above and hence it necessitates multiple testing. At the time of writing this report, there were no standardized tests method or equipment adopted by ASTM. Below is a list of test methods for workability properties of SCC that has been employed in the past. These equipments and test method have been employed by many researchers and agencies to investigate SCC rheology in past with good success and experience. It is expected that these equipment will be adopted "as-is" and standardized without much dimensional alterations.

Table 1 Test methods for workability properties if SCC

Test Method	Property Measured
Slump-flow	Filling ability
T_{50}Slump-flow	Filling ability
J-Ring	Passing ability
V-funnel	Filling ability
V-funnel at $T_{5\ minutes}$	Segregation resistance
L-box	Passing ability
U-Box	Passing ability
Fill-box	Passing ability
GTM screen stability test	Segregation resistance
Orimet	Filling ability

Below is a short description of these workability test methods.

1.3.1.1 Slump-Flow Test

Slump-flow tests are used to determine flowability and stability of self -Consolidating concrete. The equipment consists of one slump cone and one flow table (Figure 1). A concentric diameter of 500 mm is marked on the table. The slump cone is filled with concrete while pressing the slump cone to the table. Next, the slump cone is lifted vertically and time measurement is started. Time for the concrete diameter to reach 500mm (T_{50}) is recorded. When the concrete has stopped flowing, the final diameter (D-final) of the concrete and if necessary any segregation border at the concrete periphery is measured, see Figure 1.

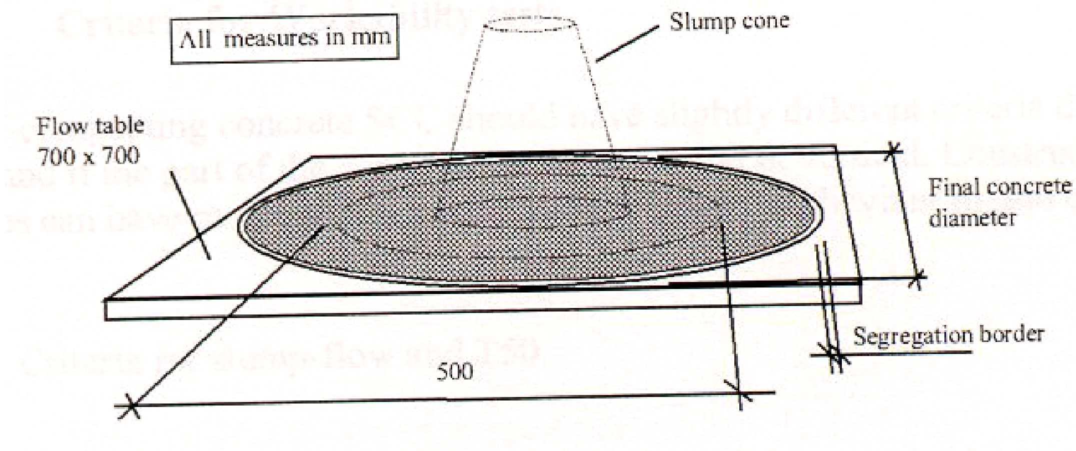


Figure 1 Slump Flow test Apparatus

1.3.1.2 J-Ring test

The test is used to determine the passing ability of the concrete. The equipment consists of a open steel ring, drilled vertically with holes to accept threaded sections of reinforcement bar. These sections of bar can be of different diameters and spaced at different intervals. The diameter of the ring of vertical bars is 12in (300mm), and the height of 4in (100 mm). The JRing can be used in conjunction with the Slump flow or the Orimet test. These combinations test the flowing ability and (the contribution of the JRing) the passing ability of the concrete. After the test, the difference in height between the concrete inside and that just outside the JRing is measured. This is an indication of passing ability, or the degree to which the passage of concrete through the bars is restricted.

The JRing is placed centrally on the base-plate with the slump-cone. The cone is filled without tamping and lifted vertically to allow the concrete to flow out freely. The final diameter of the concrete in two perpendicular directions is measured. The difference in height between the concrete just inside the bars and that just outside the bars is also measured. Slump flow with or without J-ring can be measured.

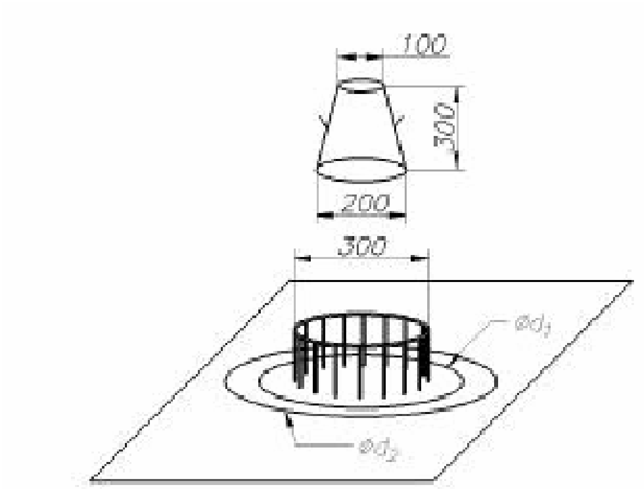


Figure 2 J-Ring test apparatus

1.3.1.3 V-Funnel test

V-funnel test is used to determine flowability and stability of SCC. The equipment consists of a v-shaped funnel according to Figure 3. The v-funnel is filled to its upper level with concrete. After the concrete rests for one minute in the v-funnel, the gate is opened. Time for the concrete to flow out of the v-funnel (Flow-time) is recorded. The concrete is observed while it flows out and any blocking leading to total stoppage of flow or temporary stops is noted

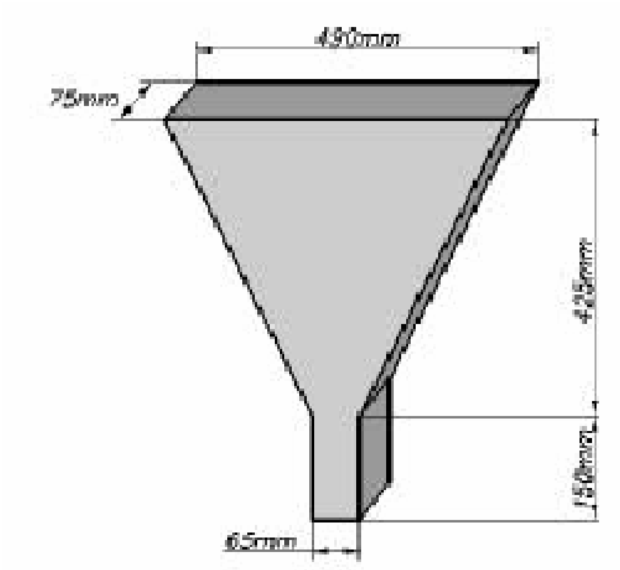


Figure 3 V-Funnel test apparatus

1.3.1.4 L-Box Test

The principles of the L-shaped box are shown in Figure 4. With the L-shaped box, it is possible to measure different properties, such as flowability, blocking and segregation. The vertical part of the box, with the extra adapter mounted, is filled with concrete. After the concrete has rested in the vertical part for one minute, the sliding gate is lifted. The concrete will now flow out of the vertical part into the horizontal part of the L-box. On its way, it has to pass the layer of reinforcement. The gap between reinforcement bars is 1.5in (34 mm), but can be changed to other gap sizes. After the sliding gate is removed the time for the concrete front to reach 8in (200mm) marking (T_{20}), and the time for the concrete front to reach 16in (400mm) marking, see Figure 3 (T_{40}) is recorded.. When the concrete has stopped; the distances H_1 and H_2 at 8in and 16in mark are measured. Acceptable values of the so-called blocking ratio, H_2/H_1, can be 0.80 – 0.85. Both blocking and stability can be detected visually. If the concrete builds a plateau behind the reinforcement layer, the concrete has either blocked or segregated. Blocking usually displays it self by coarse aggregates gathered between the reinforcement bars. If coarser aggregates are distributed on the concrete surface all the way to the end of the horizontal part, the concrete can be regarded as stable.

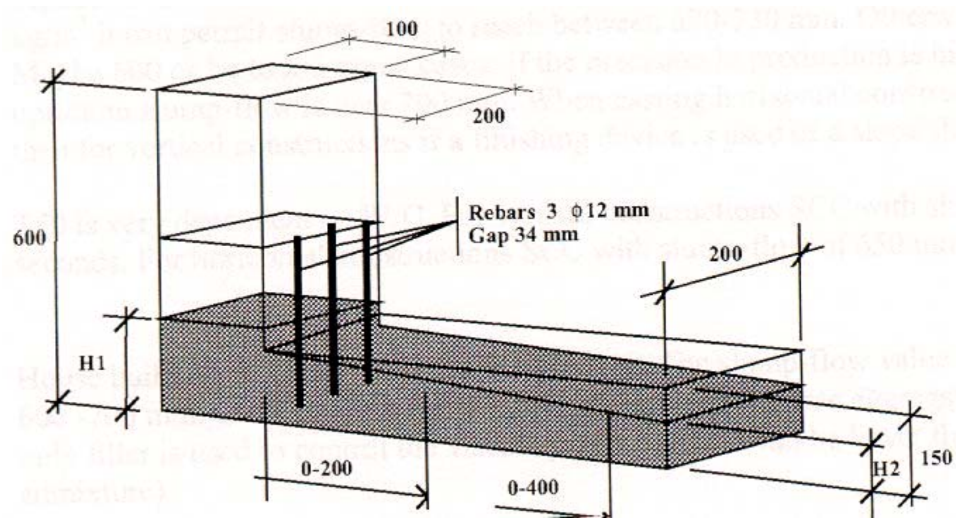


Figure 4 L-Box flow Test Apparatus

1.3.1.5 U-Box Test

The test is used to measure the filling ability of self-consolidating concrete. The apparatus consists of a vessel that is divided by a middle wall into two compartments, shown by R_1 and R_2 in Figure 5. An opening with a sliding gate is fitted between the two sections. Reinforcing bars with nominal diameters of 0.5in (13 mm) are installed at the gate with center-to-center spacing of 2in (50 mm). This creates a clear spacing of about 1.5in (35 mm) between the bars. The left hand section is filled with concrete then the gate lifted and concrete flows upwards into the other section. The height of the concrete in the second section is measured. When the concrete stops flowing, the heights “H_1” and “H_2” in both compartments are measured. H_1 - H_2, the filling height is calculated.

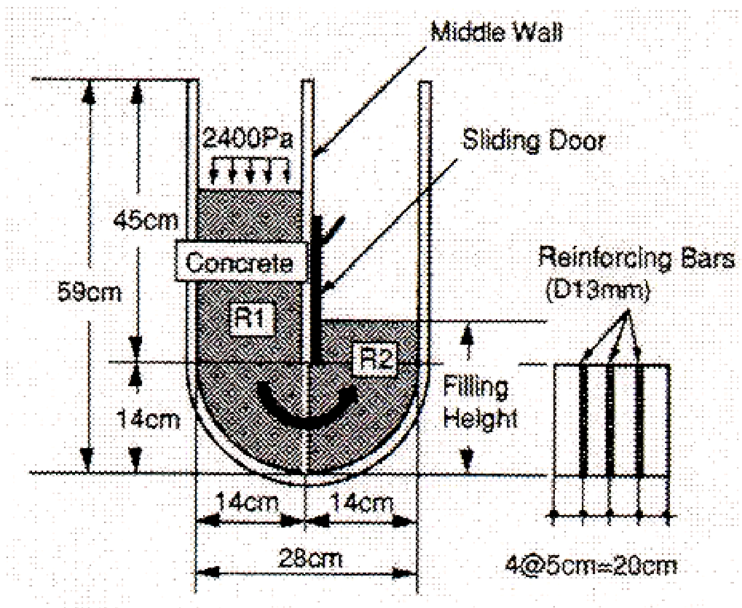


Figure 5 U-box Test Apparatus

1.3.1.6 Fill-Box test

The apparatus consists of a container (transparent) with a flat and smooth surface. In the container there are 35 obstacles made of PVC with a diameter of ¾in (20mm) and a distance center to center of 2in (50mm). At the topside is a filling pipe (diameter 4in (100mm) and height 20in (500mm)) with a funnel (height 4in (100mm)). The container is filled with concrete through this filling pipe and the difference in height between two sides of the container is a measure for the filling ability.

1.3.1.7 GTM Screen Stability Test

This test has been developed by the French contractor, GTM, to assess segregation resistance (stability). It consists of taking a sample of 10 liter of concrete, allowing it to stand for a period to allow any internal segregation to occur, then pouring half of it on to a 5mm sieve of 350mm diameter, which stands on a sieve pan on a weigh scale. After two minutes, the mortar, which passed through the sieve, is weighed, and expressed as a percentage of the weight of the original sample *on* the sieve. Calculate the percentage of the sample passing the sieve called the segregation ratio.

1.3.1.8 Orimet Test

The Orimet was developed at the University of Paisley as a method for assessment of highly workable, flowing fresh concrete mixes on construction sites. The equipment is shown in figure 5. The test is based on the principle of an orifice rheometer. The Orimet consists of a vertical casting pipe fitted with a changeable inverted cone-shaped orifice at its lower, discharge end, with a quick-release trap door to close the orifice. Usually the orifice has an 80 mm internal diameter, which is appropriate for assessment of concrete mixes of aggregate size not exceeding 20 mm. Orifices of other sizes, usually from 70 mm to 90 mm in diameter, can be fitted instead. Operation consists simply of filling the Orimet with concrete then opening the trapdoor and measuring the time taken for light to appear at the bottom of the pipe (when viewed from above).

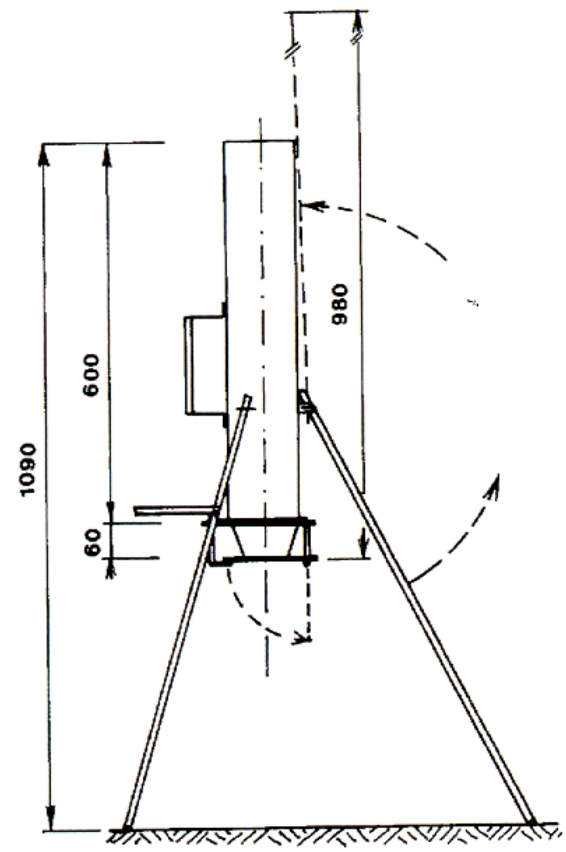


Figure 6 Orimet test Apparatus

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

An extensive literature review pertaining to Self-Consolidating Concrete (SCC) was conducted. A wealth of information was found in the literature and was studied with respect to different aspect of SCC, such as, fresh concrete, harden concrete properties and mixture proportioning methods. Below is a short summary of various reports, paper and article that were found to relevant to this study.

2.2 Mixture Proportioning Procedures

There are many procedures available in literature for proportioning Portland cement concrete. ACI absolute volume method of mix proportioning [[1]] is one of the most commonly used procedures by the concrete industry. Due to special needs of SCC in its fresh state, the procedure used for normal concrete proportioning requires modification or alteration. Typically, SCC in harden state has same requirement as normal concrete and it is the fresh state that poses much challenge to the designer.

Generally, there are three different concepts of designing and producing SCC. SCC can be produced using high powder content (powder type), using Viscosity Modifying Agents (VMA type) or combination of the two (combination type). Generally SCC also require higher dose of superplasticizer as compared to normal concrete.

Powder type SCC is popular in European countries due to readily available bended cement with desire powder contents. Viscosity of SCC can be increased with fillers such as flyash, glass filler, limestone powder, silica fume and quartzite filler. In North America, VMA type SCC is most popular with many manufacturers of VMA agents readily available.

SCC in its fresh state requires high fluidity and segregation resistance ability among other important requirements. Okamura [2] initially proposed a method, which requires tests to be conducted on cement paste and mortar for their properties and compatibility of various ingredient materials. However this was not found convenient for ready-mix concrete producers and Japanese Ready-Mixed Concrete Association (JRMCA) [3] proposed a standardized mix design method of SCC based on Okamura's procedure. Table 2 below shows the specification proposed by Japanese Society of Civil Engineering (JSCE) [4].

Laboratory Central Des Ponts et Chausses (LCPC) [5], the Swedish Cement and Concrete Research Institute (CBI), has developed a mix design procedure based on BTRHEOM rheometer and related software.

In Taiwan, the method proposed by Hwang [6] involves a densified mixture design algorithm, which is derived from the maximum density theory and excess paste theory.

Table 2 SCC Specification of Japanese Society of Civil Engineering.

Class of filling ability of concrete		1	2	3
Construction Condition	Min gap between reinforcement (mm)	30-60	60-200	>200
	Amt of reinforcement (kg/m^3)	>350	100-350	<100
Absolute vol of coarse aggregate per unit vol of SCC (m^3/m^3)		0.28-0.30	0.30-0.33	0.3-0.36
Flowability	Slump flow (mm)	650-750	600-700	500-650
Segregation resistance	Time to flow through V-funnel (s)	10-20	7-20	7-20
	Time required to reach 500 mm slump flow (mm)	5-25	3-15	3-15

Nau Su proposed a simple mix design methods in [7]. The main focus of the method is fill voids in loosely filed mineral aggregate with paste of binder. The procedure is summarized as below.

Step 1: Calculate the coarse and fine aggregate contents

Step 2: Calculate the cement content

Step 3: Calculate mixing water based on cement content

Step 4: Calculate Flyash and GGBFS contents

Step 5: Calculate the mixing water needed in SCC

Step 6: Calculate the Superplasticizer dosage

Step 7: Adjust Mixing water due to aggregate moisture

Step 8: Trial Mixes and test SCC properties

Step 9: Adjust Mix proportion

Author defined the packing factor (PF) of aggregate used in Step 1 as the ratio of mass of aggregate of tightly packed state in SCC to that of loosely packed state. A higher PF, indicates greater amount of aggregate content, which will require less binder and generally will have less flowability and vice versa. JSCE recommends minimum amount of cement for producing normal and the high durability concrete as 455 lb/yd^3 (270 kg/m^3) and 490 lb/yd^3 (290 kg/m^3), respectively. Upon conclusion of the study, the author found that the aggregate PF determines the aggregate content and influences the strength, flowability and self-consolidating ability. In their design method, the volume of sand to mortar was in the range of 54-60% and they found that PF value was the controlling fact for filling height of U-box test.

A. Saak et al [8] presented a new segregation-controlled design methodology. The theory assumes that for a given aggregate particle size distribution and volume fraction, the rheology and density of the cement paste matrix dictate the fluidity and segregation resistance of concrete. It was also concluded that a minimum paste yield stress and viscosity must be exceeded to avoid segregation under both static and dynamic conditions, respectively. Authors defined a segregation-resistant and yet high workability region as rheological self-flow zone (SFZ). The applicability of the theory for designing SCC was tested by measuring flow properties of concrete using U-Box. The aggregate particle size distribution and volume fraction were held constant and the yield stress, viscosity and density of cement paste were measured.

Su, J. K. et al [9] studied the effect of sand ratio (fine aggregate volume/total aggregate volume) on the elastic modulus of SCC. Various SCC mixes with differing S/A ratio were cast and tested. Elastic moduli were compared to normal concrete.

Authors concluded that the flowability increased with S/A ratio and elastic modulus of not significantly affected by S/A ratio when total aggregate volume was kept constant.

Sari, M. [10] presented a new method based on the use of two admixtures: a nanometric, amorphous, silica SiO_2 (for reactivity with cement paste), combined with a specific polysaccharide (for its suspending ability). The process involved enriching the granular skeleton of the mix with ultra fine elements by using precipitated silica slurry and keeping aggregates well suspended by using liquid form polysaccharide. The trials confirmed the feasibility of high strength concrete mix designs with demoulding time as short as 10 hours and concrete with excellent finish.

Bui V. K. et al. [11] presented a simple apparatus and a rapid method for testing segregation resistance of SCC. The extensive testing showed the usefulness of this apparatus in assessing the segregation resistance in both vertical and horizontal direction. For evaluating the vertical segregation resistance, the conventional compacting factor test apparatus is used, while for horizontal segregation resistance, horizontal leg of L-Box is used. A penetration test with a head of 1.9oz (54g) weight is then performed on these collected samples. The samples are then washed and particles larger than 0.37in (9.5mm) are separated, dried and weighed. The average mass of the coarse aggregate is calculated and compared. A difference of 10% or less between samples from front of reinforcement bars and end of L-box indicates satisfactory segregation resistance. It was proposed that concrete with penetration depth (measured after 45s of releasing the head) of less than equal to 0.31 (8mm) would have satisfactory segregation resistance.

Bauzoubaa N. et al [12] studied 10 mixes of varying w/c ratio and fly ash content and presented the findings of fresh and harden concrete properties. W/c ratio varied from 0.35 to 0.45 and flyash replacement was varied from 40% to 60%. Slump test and v-funnel test were conducted to measure flowability. The segregation test developed by Fujiwara consisting of gently pouring a 0.53 gallon (2 liter) container of fresh concrete over a 0.2in (5mm) mesh, and measuring the mass of the mortar passing the screen after 5 min was also performed. A stable concrete should not pass more 5% segregation index. In addition to this, bleeding, setting time and autogenous temperature rise were also monitored.

Ho, D, et al.[13] studied the utilization of quarry dust for SCC applications. Rheological measurements on pastes and mixes were made and compared to SCC mix with limestone powder. It was found that quarry dust could be used for SCC production, but required higher dosage of superplastizer.

Okamura and Ozawa developed a mix design method in Japan in 1995, which is based on the characteristics of material used, and their mix proportions [14]. The coarse and fine aggregate content are fixed while the water-cementitious ratio and superpasticizers content is adjusted to achieve self-consolidation in the fresh concrete. Typical steps involved are

Step 1: The coarse aggregate content is fixed at 50% of solid volume of the concrete

Step 2: the fine aggregate content is fixed at 40% of the mortar volume

Step 3: w/c ratio is assumed to be 0.9-1.0% by volume depending on the properties of the binders

Step 4: the superplasticizer dosage and final w/c ratio are determined to ensure self-consolidation.

Petersson and co-workers [15] developed a model for mix design of SCC and involve following items:

Void content: The minimum paste volume required for coarse and fine aggregate is calculated by measuring the void content for different combinations of coarse and fine aggregate using the modified ASTM C 29 method. The minimum paste volume should fill and voids between aggregate particles while covering all aggregate particles surfaces.

Blocking criteria: A model to calculate the limiting total aggregate content of a non-blocking concrete mix was developed based on grading and maximum aggregate size.

Mortar Proportions: The optimum proportions of the mortar within the mix is determined by adjusting the w/cm ratio, superplasticizer, viscosity-modifying agents and sand content until the required yield shear stress and plastic viscosity are obtained using the viscometer.

Concrete Proportions: Mix proportions are then determined by means of the model developed for calculating the maximum total aggregate content of a mix without the risk of blocking.

Sedran [16] proposed mix deign method based on solid suspension model. The principle of solid suspension model is that part of the water in concrete is used to fill the voids between the skeleton (binder and coarse aggregate); the remainder is used to control the workability. By minimizing the void space between the Skelton, the workability of a mix can be increased for same water content. This model can predict the packing densities of combined dry materials from their indicial bulk densities, grading, curve, packing density and mass proportion in combination. A rheometer (BTRHEOM™) was developed to measure the shear yield stress and plastic viscosity of the concrete and mortar. The mains steps of the method are as follows:

Step 1: Specification of the concrete is determined on the basis of slump flow or using the BTRHEOM.

Step 2: A combination of binders is fixed based on previous knowledge to satisfy compressive strength requirement and material availability

Step 3: The saturation level is determined and half this amount is used to prevent segregation

Step 4: The water demand of the binder combination with superplasticizer is determined with previous knowledge of material properties and water reduction effect.

Step 5: The solid Suspension Model is used to optimize the proportions of binder and aggregate. The water content is minimized and an arbitratorily relative viscosity if chosen

Step 6: A sample of concrete is batched and water concrete is adjusted to obtain the target viscosity

Step 7: The superplasticizer dosage is adjusted to achieve a suitable slump flow

Step 8: The potential compressive strength of the concrete may be calculated using the generalized Fret's formula

Step 9: The fresh properties of the concrete such as filling and passing ability are studied.

2.3 Examples of SCC mix Design around the World

Following tables illustrate the typical SCC mix types and their typical composition around the world[17].

Table 3 Examples of SCC Mixes in Japan.

Ingredients	Mix J1 (Powder type)	Mix J2 (VMA Type)	Mix J3 (Combination Type)
Coarse Aggregate	1327	1388	1469
Fine Aggregate, lb	1263	1463	1181
Cement, lb	891	370	502
Fly Ash, lb	118	0	346
Silica Fume, lb	0	0	0
Ground Granulated Blast Furnace Slag, lb	0	484	0
Water, lb	294	278	294
HRWR, lb	15.29	7.65	17.6
VMA, lb	0	6.88	0.15
Slump Flow test Spread, in	24.6	23.6	23.6

Mix proportions are for 1 yd^3 of concrete

Table 4 Examples of SCC Mixes in Europe

Ingredients	Mix E1 (Powder type)	Mix E2 (VMA Type)	Mix E3 (Combination Type)
Coarse Aggregate	1261	1261	1261
Fine Aggregate, lb	1455	1463	1177
Cement, lb	471	555	521
Fly Ash, lb	0	0	320
Limestone Powder, lb	412	0	0
Silica Fume, lb			
Ground Granulated Blast Furnace Slag, lb	0	226	0
Water, lb	320	323	336
HRWR, lb	7.03	9.94	10.93
VMA, lb	0	0	12.46
Slump Flow test Spread, in	23.6 - 29.5	23.6 - 29.5	23.6 - 29.5

Mix proportions are for 1 yd^3 of concrete

Table 5 Examples of SCC Mixes in USA.

Ingredients	Mix U1 (Powder type)	Mix U2 (VMA Type)	Mix U3 (Combination Type)
Coarse Aggregate	1038	1153	1504
Fine Aggregate, lb	1773	1578	1711
Cement, lb	688	602	701
Fly Ash, lb	76	0	0
Silica Fume, lb	0	0	0
Slag, lb	0	201	0
Water, lb	293	303	260
HRWR, ml	1602	2500	2616
VMA, lb	0	0	542
Slump Flow Spread, in	28	26	24

Mix proportions are for 1 yd^3 of concrete

2.4 Viscosity Modifying Admixtures (VMAs)

The viability of SCC was greatly increased upon introduction of Viscosity Modifying Admixtures (VMAs) in late 1990's. There are two basic types of VMAs[18]

1. traditional pumping aids chemically based on modified cellulose or hydrolyzed starches
2. Polyethylene -glycol and biopolymers which appear to be most effective for SCC

Hydrogen bonds between two glycoside rings causes significant increase in the viscosity of aqueous phase and these polymers are readily adsorbed on the surface of cement particles. The resulting bridging effect increases the yield stress of the cement paste and the subsequent cohesiveness of concrete mixture at rest or under moderate shear stress.

Khayat, K. [19], provided an excellent overview of viscosity enhancing admixtures (VEAs) used for cement-based materials. He concluded that by adjusting the combination of VEAs and HRWR, a fluid, yet washout-resistant, system can be produced. This can enhance in situ properties of underwater-cast grout, mortar, and concrete, reduce the turbidity, and increase pH of the surrounding water.

Rixom R. [[20]] discussed the four areas where concrete chemical admixtures have made an economic impact on the concrete industry. Admixtures presented included, air entraining admixtures, water reducing agents, superplasticizers (with respect to SCC) and accelerator. It cited a study that documented the savings in labor time at each stage of production of residential concrete slabs. An overall labor savings of 33% and improved quality of concrete in terms of compressive and flexural strength and flatness was observed.

2.5 Selecting The Appropriate SCC Performance Targets

Constantiner, D. describes a practical framework for the selection of flowing properties that will best suit an application and deliver optimum performance. First the applications are classified based on ratings of various characteristics of the element being cast including flow distance, level of reinforcement, shape, potential for segregation, and appearance. These requirements are then mapped into a range of flow and stability properties of SCC. Placement techniques can also influence the mixture design process and are discussed in the paper from the perspective of SCC mixture performance. Figure 7 below shows relationship matrix between element characteristics and flow properties. Dark boxes in The Figure 7 are combinations unlikely to work.

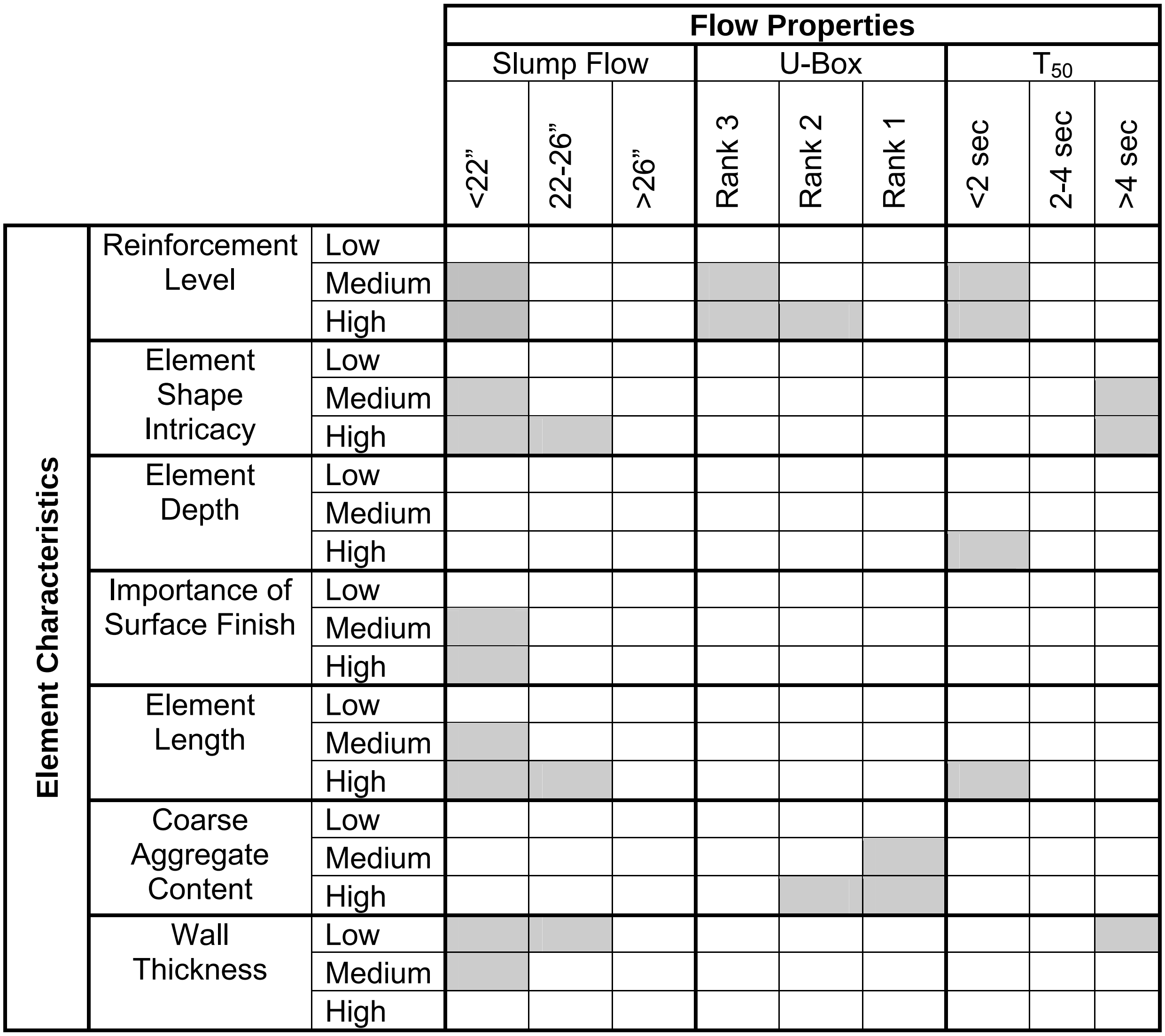


Figure 7. Relationship matrix between element characteristics and flow properties.

2.6 Guidelines and Specifications

EFNARC,[21] The European Federation of Producers and Contractors of Specialist Products for Structures, published “Specification and Guidelines for Self-Compacting Concrete” in early 2002. The EFNARC Specification defines specific requirements for the SCC material, its composition and its application. The Annexes also include a wealth of useful advice to designers, concrete manufacturers, contractors, specifying authorities and testing organizations.

Peterson et al, [22] under Brite-EuRam project BRPR-CT96-0366 titled "Rational Production And Improved Working Environment Through Using Self Compacting Concrete" has produced extensive reports on various aspects of SCC. The project was subdivided in two parts. The first part was concerned with the development of self-compacting concrete with or without steel fibers. The second part dealt with full-scale experiments in civil engineering and housing. The main target was to develop production and transport methods suitable for the SCC and to optimize construction site organization to achieve more competitive production and lower construction costs. The results from the work showed that it is possible to produce a self-compacting concrete both with and without steel fibers and that, the estimated cost for self-compacting concrete seems reasonable. The useful reports on various completed task are available online at http://scc.ce.luth.se/.

PCA recently updated its bibliography series [23] pertaining to SCC and includes over 250 references to technical reports, journal articles, conference presentations, and links to web documents. A new section on "Standards and Guidelines: Established and Under Development" lists standards activities worldwide related to SCC, with links to documents and specific contact information.

Following are the references to Standards and Guidelines either established and under development:

- American Concrete Institute (www.aci-int.org) Subcommittee 236B, formed in 2002, is preparing a state of- the-art report on SCC. Subcommittee Chair, Joseph A. Daczko, Master Builders, email jdaczko@mbt.com.
- American Society for Testing and Materials (www.astm.org) Subcommittee C09.47 on Self-Consolidating Concrete, formed in 2002 to develop a standard for SCC in the U.S. Subcommittee Chair, Martin Vachon, Axim Concrete Technologies, email mvachon@essroc.com
- Brite-EuRam project BRPR-CT96-0366, Rational Production and Improved Working Environment Through Using Self Compacting Concrete, Guidelines (2000), http://scc.ce.luth.se/public/report/guidelines. BRITE (Basic Research in Industrial Technologies for Europe)-EuRam is a cooperative research program under the European Commission.
- EFNAR guidelines, "Specification and Guidelines for Self-Compacting Concrete," at http://www.efnarc.org/efnarc/publications.htm. EFNAR is a European member organization providing support in the implementation of the new European Specifications and Regulations.
- Japan Society of Civil Engineers Concrete Committee, "Recommendation for Self-Compacting Concrete" (1998). English translation available on CD, order free at http://www.jsce-int.org (under Guidelines) or email pub@jsce.or.jp.
- National Cooperative Highway Research Program, Transportation Research Board, Project 20-30, NCHRPIDEA 89: "US-Specific Self-Compacting Concrete for Bridges." Project Manager**,** Jencks, Crawford F., (202) 334-2379. The final report will provide recommended specifications and guidelines

for the design and sue of self-compacting concrete for highway structures in the U.S.

- Precast/Prestressed Concrete Institute (www.pci.org) guidelines for the use of SCC in precast/prestressed applications. Contact: Jason Krohn, PCI, (312) 360-3231.
- RILEM Technical Committee 188-CSC: Casting of Self-Compacting Concrete, formed Sept. 2000. Chair, Prof. Skarendahl (Sweden). Web site: http://www.rilem.org/tc_csc.php.

CHAPTER 3

LABORATORY TEST PROCEDURES AND RESULTS

3.1 Introduction

After the completion of the literature review, it was determined that the objectives of the project can be achieved with completion of the following three broad categories, namely, 1) investigation of flow characteristics and fresh concrete properties, 2) investigation of harden concrete properties and 3) Investigation of economic impact (cost comparison with Normal concrete) and guideline development. Within each category, following subtask were carried out.

1) Investigation of Flow Characteristics and Fresh Concrete Properties

    Literature Review

    Study the S/A ratio effect, workability test procedures

    Study the effect of Fly ash

    Study the effect of w/c ratio

    Study the effect of GGBFS

    Study the effect of Silica Fume

2) Investigation of Harden Concrete Properties

    Study the strength behavior of SCC

    Study the durability behavior of SCC

3) Investigation of Economic Impact And Guideline Development.

Study the economics of SCC

Develop the specification and guidelines for SCC using FL material

This final report summarizes the findings of fresh and harden concrete properties of SCC investigated. As noted earlier, SCC essentially uses the same material as used in the production of conventional concrete. The main difference is in the fresh state where it is highly fluid. The harden concrete properties of SCC are generally expected to be similar to that of a normal concrete with some concerns associated with drying shrinkage and creep due to higher cement content usage. These properties were not measured in this phase of the project.

3.2 Materials Used

3.2.1 Cement

All types of cement are suitable for SCC. For all mixes in this project, Type II cement meeting the requirements of the applicable AASHTO and FDOT specifications section 921 were used and were obtained from the FDoT approved supplier.

3.2.2. Coarse Aggregates

Maximum size depends on the actual application but generally limited to ¾ inch for the production of SCC. No. 67 Limestone aggregate meeting the requirements of section 901 from FDOT approved aggregate supplier was obtained and used for all the mix production. The test procedures and properties observed for this coarse aggregate are as summarized in Table 6.

Table 6 Measured Coarse Aggregate Properties

Property	**Test Procedure**	**Value**
Reducing Samples to testing Size	FM 1-T 248	-
Sampling Coarse and fine aggregate	FM 1-T 002	-
Dry-Rodded Unit Wt	FM 1-T 019	88.16 pcf
Specific gravity	FM 1-T 085	2.58
Absorption capacity	FM 1-T 085	2.15%

The particle size distribution was determined using FDOT FM1-T 027 procedure on dry samples and the results are summarized below. The Table 7 and Figure 8 show the particle size distribution along with FDOT specification for No. 67 coarse aggregates. The results of the tests verified that the aggregate met the gradation requirements of FDOT specifications.

Table 7 Coarse aggregate gradation (Percent passing)

Sieve Size	**FDOT Sect.**	**Average Percent Passing**
1	100	100
3/4	90-100	99.3
1/2	-	73.6
3/4	20-55	42
#4	0-10	4
#8	0-5	1

A typical average particle size distribution of the used coarse aggregate is shown in Figure 8.

3.2.3 *Fine aggregate*

All conventional concreting sands are generally suitable for SCC production. Silica sand meeting the Florida State specification section 902 was used to prepare SCC mixes with properties as shown in Table 8 and Table 9.

Table 8 Measured Fine Aggregate Properties

Property	Test Procedure	Value
Specific gravity	FM 1-T 084	2.58
Absorption capacity	FM 1-T 084	0.4%
Fineness Modulus	FM 1-T 027	2.73

Table 9 Average Fine Aggregate Gradation (Percent passing)

Sieve Size	FDOT Sect.	Average Percent passing
#4	95-100	100
#8	85-100	99.99
#16	65-97	89
#30	25-70	32.4
#50	5-35	5.5
#100	0-7	0.2
#200	0-4	0.1

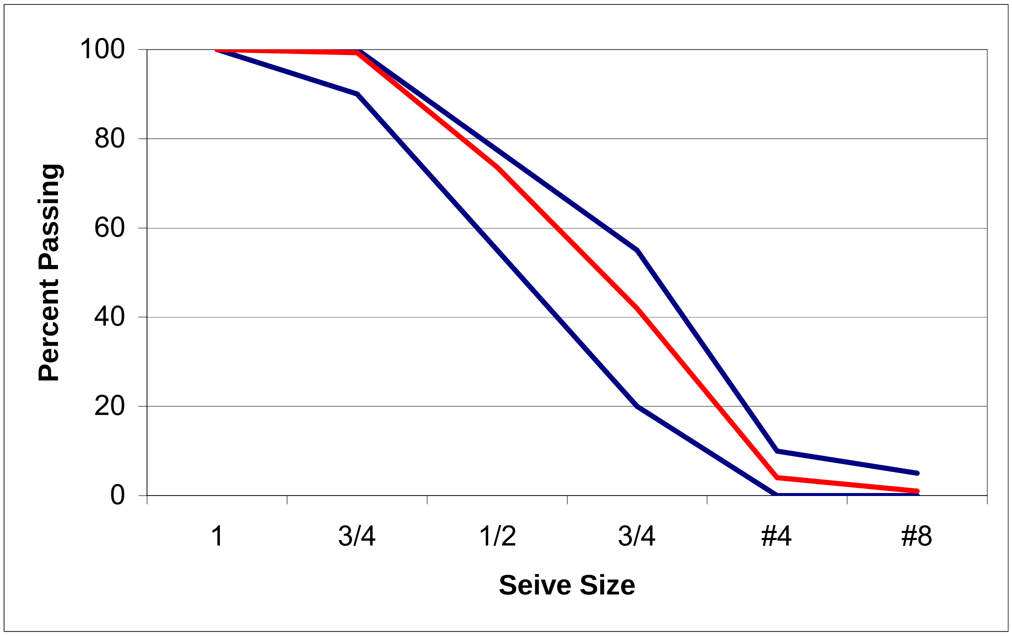


Figure 8 Average Particle Size Distribution for No. 67 Coarse Aggregate.

A typical average particle size distribution of the used fine aggregate is shown in Figure 9. The fine aggregate obtained for this project meets the FDOT specification.

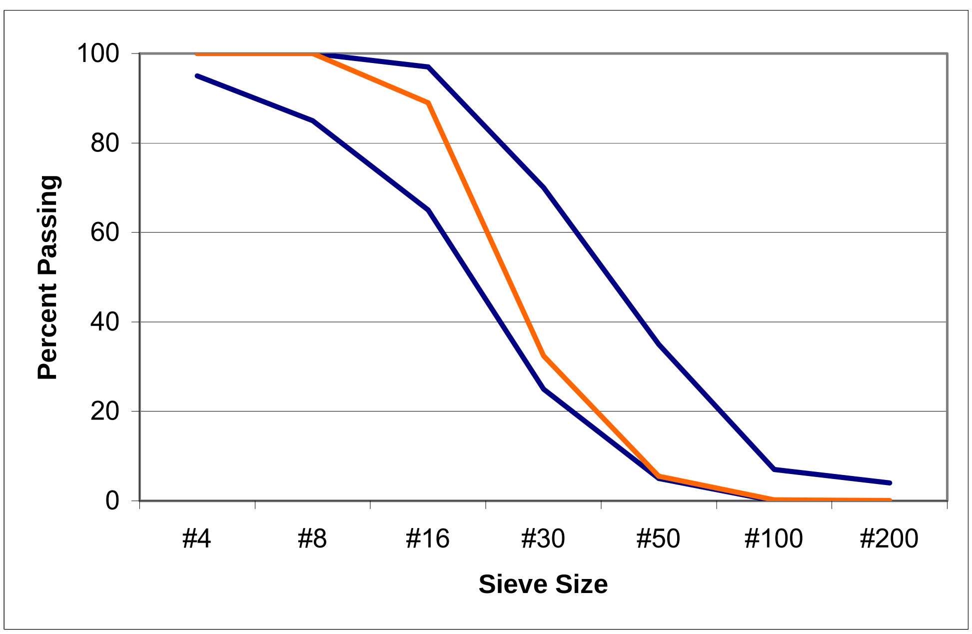


Figure 9 Average Particle Size Distribution for Fine Aggregate

3.2.4 Supplemental Cementitious Materials

Active as well as inert fine materials have been utilized to improve SCC performance and stability. Fly ash, silica fume, slag, lime rock dust, granulated blast furnace slag (GGBFS), ground glass filler etc. are some of the commonly used material. In this project effect of inert mineral such as fly ash, GGBFS and silica fume were investigated. Class F fly ash was obtained from an FDOT approved supplier and it met the applicable Florida State specification section 929. GGBFS of type 120 and Force 10,000® D, (Grace Construction Products), a dry, densified silica fume powder were also obtained from approved sources.

3.2.5 Chemical Admixtures

Chemical admixtures are essential component of any SCC. They are used to meet the necessary workability, stability and air-entrainment requirements. Of these Superplasticizers (High Range Water Reducers (HRWR) Admixtures) are most important. When mineral fillers are not used, viscosity-modifying agents (VMA) are generally necessary to impart stability to the mix. In recent past, many HRWR and VMA have been specifically developed for the use in SCC production and are readily available in the market. At the time of review, there were at least five different companies that produce and market admixtures specifically for the use in SCC and are readily available in the United States. Table 7 provides a general idea about many of the product offered by these companies with their brand names and typical dosages.

Table 10 SCC Admixtures Currently Available in the US.

Manufacturer	**Product Names™**	**Typical Dosage (oz/100 lbs)**
AXIM Concrete Technologies	Catexol SUPERFLUX 2000 PC	3-10
Euclid Chemical	Visctrol	2-20 oz/yd^3 (for 0.35-0.40) 20-60 oz/yd^3 (for 0.40-0.45)
Grace Chemicals	ADVA 530 ADVA 540	3-10
MasterBuilders	High Range Water Reducer Glenium 3000 FC Glenium 3030 NS Glenium 3200 HES Viscosity Modifying Agent Rheomac VMA 358 Rheomac VMA 362 Rheomac VMA 450	ml / 100 kg (fl.oz. / cwt) 260 – 780 (4 – 12) 65 – 1170 (1 – 18) 130 – 190 (2 – 14) 135 – 650 (2 – 10) 135 – 910 (2 – 14) 32 – 260 (0.5 – 4)
Sika	ViscoCrete 5000, ViscoCrete 6000	3-8 16 for max water reduction

Although most of these admixtures were investigated in the lab and were able to produce trial SCC mix with desired rheological properties (discussion found in next section), it was determined that it would not be practical to replicate all the design factorial for each of these admixtures separately. So a decision was made to evaluate SCC mixes for one randomly chosen SCC admixture. Axim's Superflux was thus chosen as the SCC admixture for the main study. As for HRWR, again a decision was made to use same brand of admixture for all mixes, irrespective of the manufacturer. HRWR chosen was Euclid Chemical Co's, Plastol-5000. Plastol 5000 is a HRWR that fully complies with the requirements of ASTM C-494, Type F admixture. Plastol 5000 contains no added chlorides. It was clear from the preliminary testing that the HRWR (Plastol 5000) used was compatible with all SCC admixtures tested and no harmful effect was observed on the fresh concrete properties.

Rheological test apparatus are not readily available in the market, but were simple enough to fabricate. The equipment such as L-box, U-Box, V-Funnel, J-Ring, flow table were fabricated in the lab using flexi glass and wood as appropriate with generally accepted dimensions determined from the literature review.

3.3 Mixture Proportioning

The American Concrete Institute (ACI) method [[1]] was adopted to obtain the control mixture proportion. These proportions were then adjusted to provide the desire "Sand-to-Total Aggregate" (S/A) ratio while maintaining the original total aggregate volume. S/A value ranged from a low of 0.45 to high of 0.55 in 0.025 increments where appropriate.

3.4 Influence of Sand-to-Total-Aggregate Ratio

SCC generally requires high fine content and or viscosity modifying admixtures. One the important factor affecting SCC rheological behavior is the sand to total aggregate ratio (S/A ratio). Conventional concrete has a typical S/A ratio ranging from 0.35 to 0.45 by volume. Such conventional concrete can be made flowable using appropriate admixtures but generally has very poor segregation resistance. So, the first major undertaking in this project was to determine the optimum S/A ratio, which would be eventually used to study the effect of fly ash, silica fume and GGBFS as well as evaluate the workability test apparatus and procedures.

To accomplish this, a control mix was first determined using the ACI method with consideration to the FDOT specification section 346. After, studying the minimum requirements of various classes of concrete as per FDOT specification section 346, it was decided to design a concrete mixture for a maximum w/c ratio of 0.37, a minimum cement content of 752 lb/yd^3 and target air content of 2%. Using ACI method and FM of sand, two control mixes (for two different cement content) were designed with mix proportion as shown in Table 11.

Table 11 Mix Proportion Of Control Concrete (for w/c =0.37, c=572 and 900 lb/yd^3)

	w/c =0.37	
	Cement= 752 lb/yd^3 Mix ID= A	**Cement= 900 lb/yd^3 Mix ID= B**
Coarse Agg. (lb/yd^3)	1500.00	1500.00
Fine Agg. (lb/yd^3)	1298.66	1036.35
Adjusted Water (lb/yd^3)	315.68	369.41
S/A ratio	0.464	0.409
Total Aggregate Vol.	18.175 ft^3/yd^3	16.545 ft^3/yd^3

These proportions were then modified to provide different S/A ratio ranging from 0.45 to 0.55, while maintaining the total aggregate volume to that in the two control mixes. Table 12 below shows the details of the different mixes studied. Later, the influence of fly ash was studied by substituting certain percent of cement by weight.

Table 12 Mix Proportions for S/A investigation (w/b=0.37, A=752, B=900 lb/yd^3)

Designation	S/A	Cement lb	Fly Ash lb	Coarse Agg. lb	Fine Agg. lb	Water lb
A (control)	0.464	752	-	1500	1298.66	315.68
A50	0.50	752	-	1403.4	1403.4	314.03
A525	0.525	752	-	1336.00	1476.60	313.63
A55	0.55	752	-	1268.20	1550.10	311.71
A525F1	0.525	676.8	75.20 (10%)	1336.00	1476.60	313.63
A525F2	0.525	601.6	150.4 (20%)	1336.00	1476.60	313.63
A525F3	0.525	526.4	225.6 (30%)	1336.00	1476.60	313.63
B (control)	0.409	900	-	1500.00	1036.35	369.41
B45	0.45	900	-	1399.5	1145.25	367.65
B47	0.475	900	-	1338.75	1211.40	366.75
B50	0.50	900	-	1277.55	1277.55	365.58
B52	0.525	900	-	1216.35	1344.15	364.50
B55	0.55	900	-	1154.70	1411.20	363.47
B45F	0.45	720	180 (20%)	1399.5	1145.25	367.65
B475F	0.475	720	180 (20%)	1338.75	1211.40	366.75
B50F	0.50	720	180 (20%)	1277.55	1277.55	365.58
B525F	0.525	720	180 (20%)	1216.35	1344.15	364.5
B55F	0.55	720	180 (20%)	1154.70	1411.20	363.47

* Mix proportions are for 1 yd^3 of concrete

3.4.1 Mixing Procedure

All Concrete batches were prepared in rotating drum mixer. First, the aggregates are introduced and then one-half of the mixing water was added and rotated for approximate two minutes. Next, the cement (and fly ash where applicable) were introduced with HRWR admixture already mixed in the remaining water. VMA and any additional amount of superplasticizer were introduced in the rotating drum as needed. Most manufacturers recommend at least 5 minutes mixing upon final introduction of admixtures.

Once, the mix was determined to have sufficient visual attributes of SCC, the rheological tests were performed in quick succession. Typically, the order of testing employed was as follows:

1. U-box (height of concrete in each compartment)
2. V-funnel (time to empty)
3. L-Box (T20, T40 and heights at 20 and 40cm)
4. Flow Test with Inverted Cone (spread and T50)
5. Flow Test with Regular Cone (spread and T50)
6. density (Unit weight)
7. Air Determination (using pressuremeter)
8. Casting of Specimens

After the flow test was conducted, concrete's visual stability index (VSI) was determined. Criteria used for VSI rating is described in Table 10.

Table 13 Visual Stability Index (VSI) Rating Criteria

VSI	Criteria
0	No evidence of segregation in slump flow patty, mixer drum or wheelbarrow
1	No mortar halo in slump flow patty, but some bleeding on the surface of concrete mix drum or wheel barrow
2	A slight mortar halo (<3/8in (10mm)) in slump patty and noticeable layer of mortar on the surface of resting concrete in mixer
3	Clearly segregating by evidence of large mortar halo(>3/8in (10mm)) and a thick layer of mortar and bleed water in the surface of resting concrete.

3.4.1 L-Box Index

L-Box Index, I_L, is defined as the ratio of heights of concrete at 8in (200mm) and 16in (400mm) mark after the concrete has stopped moving. An index of 1.0 indicates a self-leveling concrete. Generally, an index of 0.8 or higher indicates an excellent flowability in SCC.

3.4.2 U-Box Index

U-Box Index. I_U, is defined as the ratio of heights of concrete in the two compartments of U-box after the concrete has stopped moving. Again, an index of 1.0 indicates a self-leveling concrete. Generally, an index of 0.8 or higher indicates an excellent flowability in SCC. Traditionally, the SCC worthiness is measured from the heights recorded during these tests and since the concrete volume used could differ slightly between tests, these proposed indexes provide an easier visualization and usage.

3.5 Experimental Findings

The rheological test results of the mixes studied are summarized in Table 14 below. As can be seen from Table 14, it was found difficult to obtain a concrete mix that met all the SCC attributes readily at 752 lb/yd^3 cement content. With fly ash substitution, the results were much more favorable. At 900 lb/yd^3 cement content, it was observed that a SCC type concrete could be obtained at most levels of S/A ratio. The quality of SCC dramatically improved with increased S/A ratio. It was generally observed that if the mix passes the U-box test, i.e., if the concrete self-level on both sides of U-box, it will generally pass other test favorably. Part substitution of cement with fly ash favorably contributed to all aspect of fresh concrete tests. Presence of fly ash reduced the air content, improved stability of concrete and made concrete more viscous and segregation resistance.

Also, noted was the fact that for mixes without fly ash and lower cement content, the measured air content were excessive and typically in the range of 8-10%. Upon stopping the mixer, these concrete would “bubble” for certain duration and air would continue to escape during regular handling.

Photograph 1 Typical low fine unstable mix with excessive bleeding

Photograph 2 Typical Spread Test Result For An Unstable Mix

Photograph 3 Example of a mix with VSI rating of 3

Photograph 4 A Typical Stable Showing Homogenity.

Photograph 5 Example of a mix with VSI rating of 0

Photograph 6 A mix with No passing Ability (in L-box).

Photograph 7 A mix with Extremely high Passing Ability (Self levels)

Photograph 8 A mix with No Passing ability (in U-Box)

Table 14 Rheological Test Results Of S/A Ratio Investigation.

Mix ID	VMA (ml)	HRWR (ml)	Air (%	Unit Weight (lb/ft^3)	Slump Time		Slump Spread		U-Box	L-Box			V-Box (s)	VSI
					Reg. (s)	Invert (s)	Reg (in)	Invert (in)	I_U	T-20 (s)	T-40 (s)	I_L		
A	500	275	10	145.3	7	NP	21.65	NP	■	■			13	3
A50	500	155	9.5	144.6	7	NP	22.00	NP	■	■			15	2
A525	120	355	10	146.1	8	NP	22.84	NP	0.583	3	6	1.0	15	1
A55	500	120	10	141.4	10	NP	22.00	NP	0.733	6	15	0.818	15	1
A525F1#	110	75	2	147.8	10	NP	24.40	NP	1.0	5	12	1.0	150	0
A525F2#	110	75	2.5	146.1	17	NP	23.23	NP	0.97	4	14	1.0	120	0
A525F3#	110	65	2	144.4	11	NP	24.80	NP	1.0	5	15	1.0	105	0
B	50	50	4	142.9	■	11	■	20.00	0.929	3	11	0.545	31	NP
B45	50	75	3.5	144.1	4	6	26.00	26.00	1.0	1	4	1.0	9	2
B475	25	75	2.5	141.0	■	17	■	20.47	■	2	5	0.75	42	NP
B50	50	75	3.5	144.8	7	7	22.00	24.01	1.0	1	3	1.0	7	1
B525	55	50	4	145.2	8	5	20.00	20.87	1.0	1	4	1.0	6	0
B55	95	95	4	143.2	4	4	25.20	24.40	1.0	1	3	1.0	8	1
B45F	Data Not Used													
B475F	45	75	3.5	143.4	-	6	-	22.00	1.0	2	7	0.824	10	1
B50F	55	90	1.5	142.8	3	3	28.35	29.13	1.0	1	2	1.0	4	3
B525F	125	50	3	142.1	3	5	29.13	25.60	1.0	2	4	1.0	22	0
B55F	50	100	5	139.2	4	5	27.55	27.16	0.962	2	4	1.0	15	0

NP=Not Performed, ■ = Blackened cell indicate failed mixes

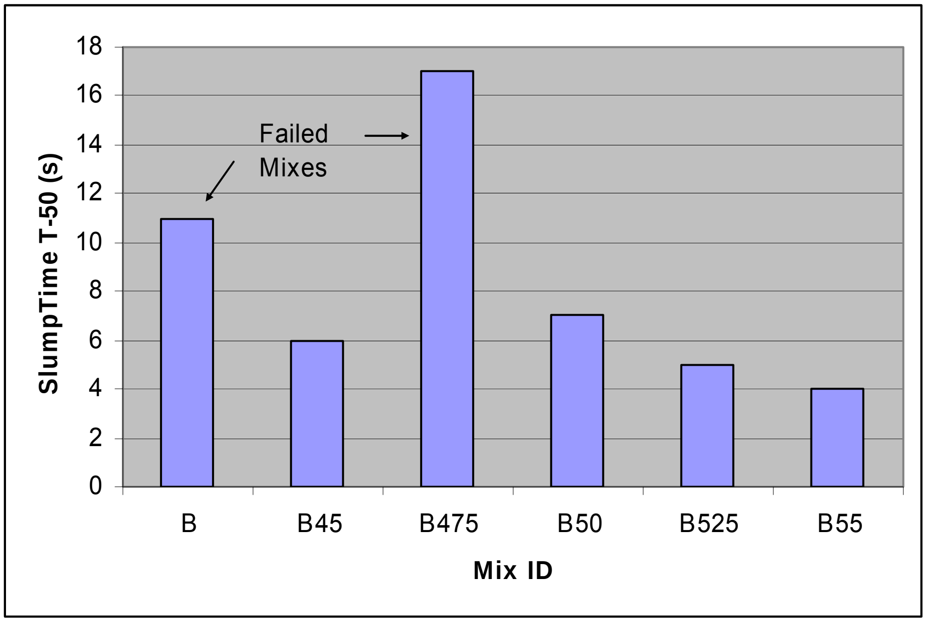


Figure 10 Slump Time for B mixes

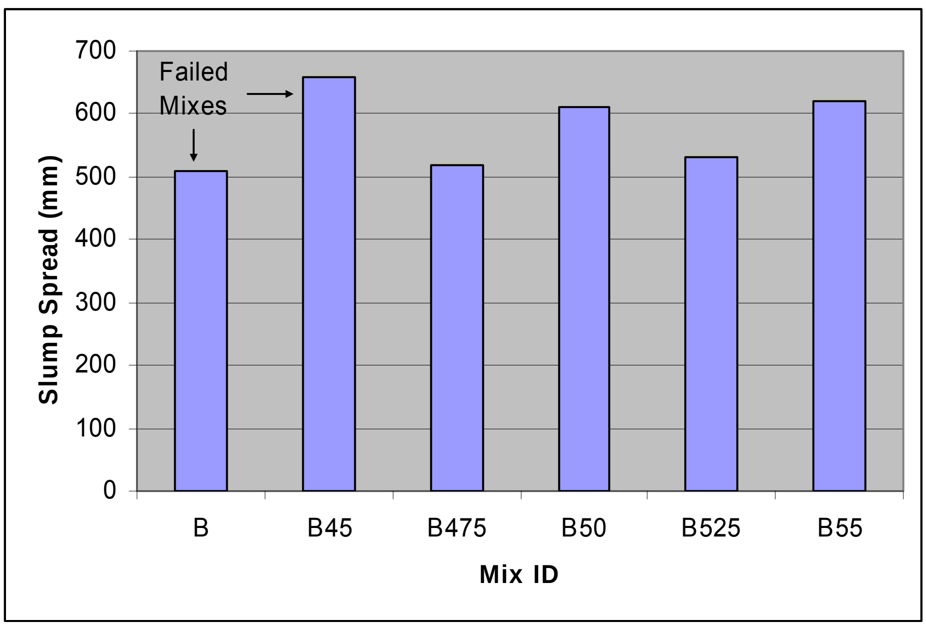


Figure 11 Slump Spread for B Mixes

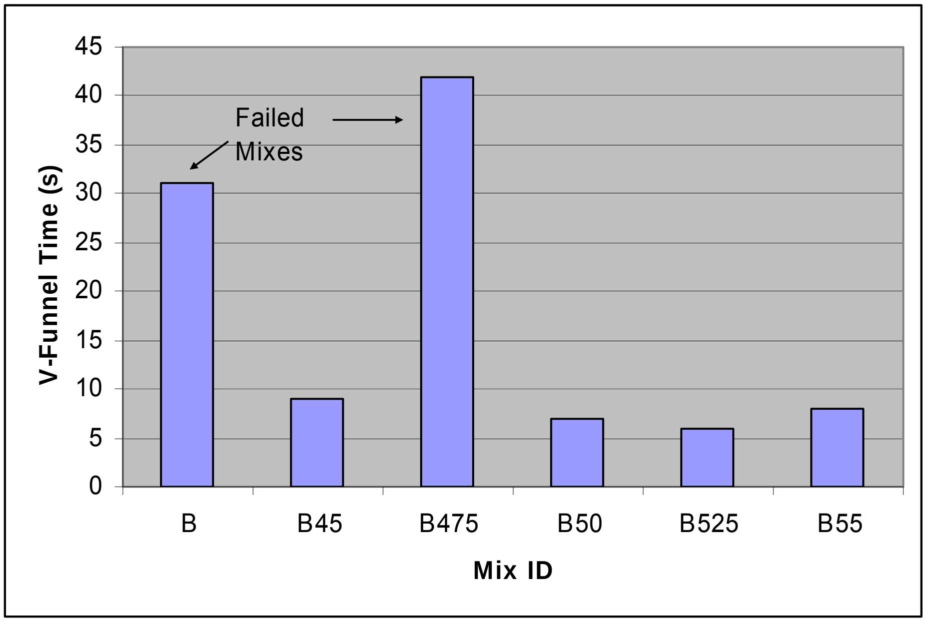


Figure 12 V-funnel Flow Time for B Mixes

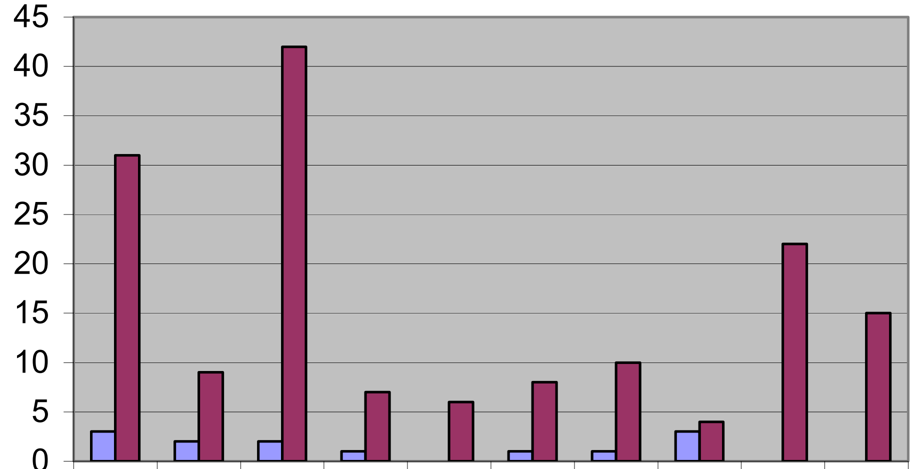
As seen from the plot above and the results of L-Box and VSI rating, a S/A from 0.5 to 0.55 is more suitable for SCC mixes. Mixes at or below S/A of 0.475 showed propensity for blocking (in L-box test) and poor stability with bleeding readily observed on the surface of freshly mixed concrete (Photographs 1-8). Based on the above observation and result of literature review, a S/A of 0.525 was adopted for the further tasks. Other researchers have also used this S/A of 0.525 in the past with success. In FDOT development specification, a maximum value of 0.50 for S/A is specified.

Also, noted was the fact that for mixes without fly ash and lower cement content, the air content measured were excessive and typically in the range of 8-10%. As seen from the Figures 9-11 and the results of L-Box and VSI rating, a S/A from 0.5 to 0.55 is more suitable for SCC mixes. Mixes at or below S/A of 0.475

showed propensity for blocking (in L-box test) and poor stability with bleeding readily observed on the surface of freshly mixed concrete. Based on the above observation and the literature review, a S/A of 0.525 was adopted for the further study.

T-50 slump flow time of 5 or less is desired and for most mixes, it was easily obtained. From the literature review and discussion with others who have worked with SCC, it was found that the spread test was done by some with cone inverted and by some with cone upright. To compare these two techniques, the spread time and slump flow were measured in both configuration and the difference was not found to be significant for concrete that meets all SCC attributes.

Also, noted was the effect of fly ash on VSI rating. Generally, for same S /A ratio, fly ash improved the VSI rating and mixes were easier to handle and were more stable. From the V-funnel data, smaller time to pass is not necessarily a good indicator of SCC properties. In fact, mixes with very low or very high V-funnel time tend to show some other problems such excessive bleeding, blockage etc (Figure 13).



	B	B45	B475	B50	B525	B55	B475F	B50F	B525F	B55F
VSI	3	2	2	1	0	1	1	3	0	0
V-Funnel	31	9	42	7	6	8	10	4	22	15

Figure 13 VSI and V-funnel Relationship

CHAPTER 4

EFFECT OF WATER-to-CEMENTITIOUS MATERIALS RATIO AND FLY ASH

4.1 Experimental Factorial

Under this task, the effect of w/c ratio, cement content and fly ash on SCC mixes were studied. Based on the findings from the previous chapter, from this point onward, the S/A ratio for all mixes was fixed at 0.525. Table 15 below shows the experimental factorial and levels of the variables chosen for this task.

Table 15 Parameters Studied for Rheological Investigation

Parameter Studied	No. of Levels	Levels
w/c ratio	4	0.3, 0.33, 0.35, 0.37
Cement content (lb/yd^3)	3	752, 825, 900
Fly ash substitution	3	0%, 10%, 20%

From the preliminary work and the earlier results of S/A ratio investigation, it was clear that some of the experimental combinations (shown as darken cells in Table 16) would be extremely difficult or even unsuccessful in nature. It was therefore decided to omit these mixes in the factorial. It was expected that these mixes were unlikely to satisfy all the SCC criteria within the manufacturers suggested dosage limits. As will be discussed latter, these expectations were found to be correct and these few mixes remained uninvestigated. It is to be noted that these omitted mixes can be given SCC attributes with much higher fly ash substitution and/or higher dosages of HRWR. Table 16 provides the experimental setup of the 27 mixes studied for this task.

4.2 Mix ID System

Following scheme to identify a particular mix will be used in this report. This should help the reader understand the mix details with ease.

Mix ID = AABBCCDD

where,

AA = w/cm ratio (1^{st} and 2^{nd} digits)

BB = % of main supplementary cementitious materials (3^{rd} and 4^{th} digits)

CC = identification of the main secondary material (two alphabets)

= FA for Fly Ash

= SF for Silica Fume

= SL for Slag (GGBFS)

DD = additional space used if necessary to introduce different variables such as total cementitious materials content of the mix or a different supplementary cementitious materials.

As an illustration, a mix with w/c ratio of 0.35, with 20% fly ash would be identified as 3520FA and a mix id 3760SL would indicate a mix with 60% slag at 0.37 w/c ratio, while a mix id of 3310FA825 would refer to a concrete mix with 10% fly ash at 0.33 w/c ratio and 825 cement content.

Table 16 Experimental Factorial to Investigate Rheological Properties and Mix IDs.

Cement Content →		752 lb/yd^3			825 lb/yd^3			900 lb/yd^3		
Fly Ash →		0%	10%	20%	0%	10%	20%	0%	10%	20%
w/c	0.3							3000FA900	3010FA900	3020FA900
	0.33				3300FA825	3310FA825	3320FA825	3300FA900	3310FA900	3320FA900
	0.35	3500FA752	3510FA752	3520FA752	3500FA825	3510FA825	3520FA825	3500FA900	3510FA900	3520FA900
	0.37	3700FA752	3710FA752	3720FA752	3700FA825	3710FA825	3720FA825	3700FA900	3710FA900	3720FA900

Nuisance Factors [24], are one of the three types of factors namely, Variable factors, Fixed factors and Nuisance factors, that affect the responses in an experiment. The variable factors and fixed factors are controlled in the experiment. However, in addition to these, there are other factors, which are not controlled in the experiment that could affect the experimental results. These so called *nuisance factors* are often assumed to do not, or should not, have any effect, but in reality, they may have an effect. Nuisance factors may include the following:

- mid-experiment changes in instruments, equipment, environmental conditions, measuring devices
- test procedures/protocols
- day of week
- time of day
- operators

Nuisance factors may affect the measured test results, which would in turn affect the data analysis, and ultimately the final conclusions. *Run sequence randomization* is used to minimize the effect of nuisance factors. Ordinarily, experiment designs are usually generated in a "standard order" based on the settings of the factors. To prevent these nuisance factor mixes were studied in a random manner. Although, run sequence randomization truly involves first generating random numbers to determine which order the experiment is to be run, for this task, mixes were prepared in an order, which avoided two neighboring mixes in a sequence. For future studies, mixes will be prepared using run sequence randomization.

4.3 Experimental Findings

Table 17 summarizes the results of rheological test performed on these 27 mixes. Mix number 3500FA752, 3510FA752 and 3300FA825 completely failed, i.e., a SCC type concrete could not be obtained within the set parameters especially the manufacturers recommended dosage limits. Mix number 3520FA752, 3000FA900 and 3010FA900 failed certain tests (U-box and/or L-Box) and were abandoned from further testing. Note that for many of these mix, multiple batches were prepared to optimize the admixture dosages.

Careful study of the data clearly reveals the importance of all three factors studied, namely, cement content, w/cm ratio and fly ash substitution. The success of achieving SCC type concrete is highly dependent on these factors. Just as was found in the previous task, fly ash has general tendency to improve or enhance SCC type properties. Fly ash, generally improved the slump flow time, reduced air content, improved performance especially in U-box and L-box.

For lower w/cm ratio, higher fly ash replacement should further improve their behavior. Careful study of the data clearly reveals the importance of all three factors studied, namely, cement content, w/cm ratio and fly ash substitution and the success of achieving SCC type concrete is highly dependent on these factors. It was observed that below 0.37 w/cm for 752 lb/yd3 cement content and below 0.35 for 900 lb/yd3 cement content, one or more attributes of SCC was not met. For these failed mixes, the VMA and HRWR dosage was incrementally increased and even exceeded beyond the recommended limits but without success. Just as was found in the previous task, fly ash has general tendency to improve or enhance SCC rheological properties.

Table 17 Rheological Test Results of w/c, cement content and flyash effect study

Mix ID	VMA (ml)	HRWR (ml)	Air (%)	Unit Weight (lb/ft^3)	Slump Time		Slump Spread		U-Box	L-Box			V-Funnel (s)	VSI
					Reg. (s)	Invert (s)	Reg (in)	Invert (in)	I_U	T-20 (s)	T-40 (s)	I_L		
3500FA752	[redacted]*													
3510FA752	[redacted]*													
3520FA752	NP*								[redacted]	3	[redacted]	[redacted]	NP	NP
3700FA752	120	355	10	146.1	7	-	22.83	-	0.583	3	6	1.0	15	1
3710FA752	120	295	2	147.8	10	NP	24.41	NP	1.0	5	12	1.0	150	0
3720FA752	120	240	2.5	146.1	17	NP	23.22	NP	0.97	4	14	1.0	120	0
3300FA825	[redacted]													
3310FA825	200	125	6	146.2	5	NP	23.62	NP	[redacted]	4	10	0.778	12	3
3320FA825	125	175	4	120.9	6	15	24.41	21.65	[redacted]	2	14	0.571	NP	1
3500FA825	50	125	8	137.5	14	12	21.25	21.65	0.862	3	10	0.722	15	1
3510FA825	50	125	5.5	142.6	60	34	19.29	20.47	0.793	3	16	0.714	26	0
3520FA825	50	150	3.5	142.1	25	21	20.87	21.65	0.857	5	44	0.500	37	0
3700FA825	95	33	8	137.6	28	14	20.08	22.44	1.0	2	7	0.823	9	1
3710FA825	125	25	5	141.9	5	5	24.80	24.40	0.963	2	6	0.750	8	1
3720FA825	75	75	3.8	143.9	7	8	24.80	24.40	1.0	2	7	0.800	14	0
3000FA900	125	450	NP	147.9	NP				0.733	[redacted]	[redacted]	[redacted]	74	NP
3010FA900	125	425	NP	145.9	NP				0.486	15	[redacted]	[redacted]	NP	NP
3020FA900	75	475	6	140.6	55	60	19.29	20.08	0.889	7	26	0.632	42	1
3300FA900	125	75	4.8	144.1	12	15	25.19	24.41	0.828	4	16	0.778	142	1

3310FA900	125	175	2.5	145.2	15	15	24.90	24.80	1.0	12	24	0.778	45	1
3320FA900	125	175	3	144.7	23	20	22.93	24.80	0.978	7	21	0.875	64	0
3500FA900	125	150	3.5	145.5	7	6	25.59	26.77	1.0	4	6	0.910	14	1
3510FA900	50	125	4	142.8	36	40	21.65	21.25	1.0	5	14	0.75	33	0
3520FA900	75	125	4	141.9	5	4	27.16	27.95	1.0	2	5	1.0	12	0
3700FA900	55	50	4	145.2	8	5	20.08	20.87	1.0	1	4	1.0	6	0
3710FA900	75	50	4	144.6	5	4	24.41	24.01	1.0	2	4	1.0	14	0
3720FA900	125	50	3	142.1	3	5	25.19	24.41	1.0	2	4	1.0	22	0

= indicates that the mix did not meet one of the SCC attribute, such as passing ability, flow ability etc.

NP=Not Performed. This could be because the mix had failed certain test and it was deemed unnecessary to conduct further testing.

Table 18 SCC Mixes Considered Failed.

Total Cementitious Materials →		752 lb/yd^3			825 lb/yd^3			900 lb/yd^3		
Fly Ash →		0%	10%	20%	0%	10%	20%	0%	10%	20%
w/cm	0.3							**FAILED**	**FAILED**	
	0.33				**FAILED**					
	0.35	**FAILED**#	**FAILED**	**FAILED**						
	0.37									

Failed means that a SCC attributes were not achieved within the recommended dosage limits.

It generally improved the slump flow time, reduced air content, improved performance especially in U-box and L-box. When compared for mixes with T_{50} time of less than 25s, spread test using inverted cone method generally resulted in similar result as in upright cone method as shown in Figure 14 (R^2=0.92). As shown in Figure 15, the U-box index and L-Box index correlated well and was observed that mixes with U-Box index of 1 (i.e., when it self levels), it will pass other tests easily.

It is the investigators opinion that U-box and L-box can adequately measure the blocking resistance of SCC and these test could be adopted “as-is” to measure blocking ability of SCC. As for as slump cone test to measure the spread time (T-50) and slump spread is concerned, the test can be performed with either the slump cone inverted or traditional (upright) way. Inverted cone offers additional advantage that a single operator can perform this test. To study if there is a difference between these two alternatives, all mixes were tested in both configurations. It was observed that these two methods provide similar results, especially for a mix that will pass the other tests such as U-box and L-Box.

SCC was placed in the molds and the top surface was finished by striking them off with wood float or trowel. The cylinders were then capped with plastic lids to prevent evaporation and loss of water from the samples.

For many mixes with high V-funnel time and high slump flow time, the specimen showed severe honeycombing. It is suggested that the samples be prepared in a single lift and sample molds slightly tilted to prevent trapping air pockets.

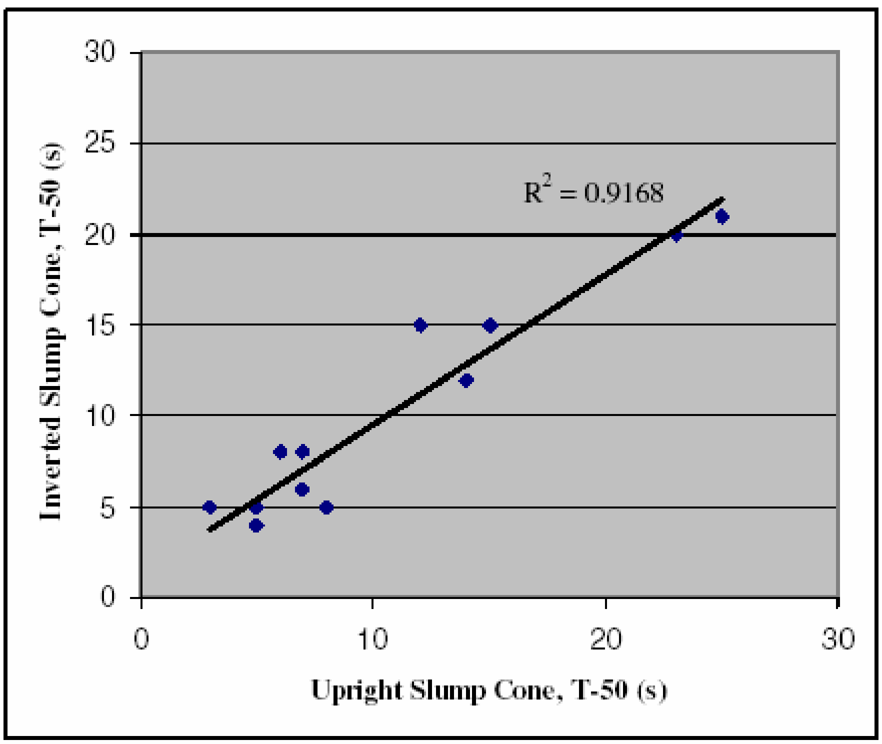


Figure 14 Relationship between Inverted and Upright Slump Cone Testing

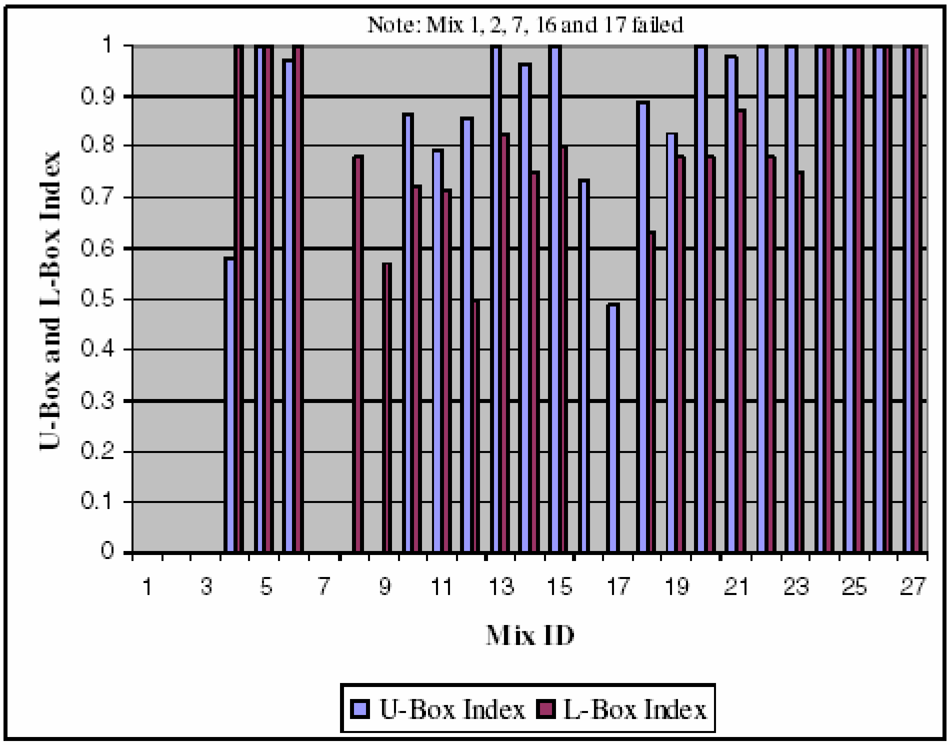


Figure 15 Relationship between L-Box and U-Box index

CHAPTER 5

INFLUENCE OF SILICA FUME

5.1 Introduction

Silica fume is a byproduct of industry producing silicon metal or ferrosilicon alloys. Due to its chemical and physical properties, it is a very reactive pozzolan and can be used in the production of concrete. Concrete containing silica fume can have very high strength and can be very durable. Silica fume consists primarily of amorphous (non-crystalline) silicon dioxide (SiO_2). The individual particles are extremely small, approximately 1/100th the size of an average cement particle. Because of its fine particles, large surface area, and the high SiO_2 content, silica fume is a very reactive pozzolan when used in concrete. Silica fume is also used for protection of concrete in contact with chlorides from deicing salts and marine environments.

For this study, Force 10,000® D, (Grace Construction Products), a dry, densified silica fume powder based on silica fume to increase concrete compressive and flexural strengths, increase durability, reduce permeability and improve hydraulic abrasion erosion resistance was used.

5.2 Experimental Factorial

To understand the effect of silica fume, a test factorial was setup for 4 levels of w/cm ratios and 3 levels of silica fume. All batches had 20 % flyash substitution. Table 19 below shows the batch identification numbers and variables levels studied to investigate the effect of silica fume in SCC.

Table 19. Experimental Matrix to Study Effect of Silica Fume.

Cementitious Content		900 lb/yd^3		
Fly Ash		**20%**	**20%**	**20%**
Silica Fume		**3%**	**6%**	**9%**
w/c	0.3	3003SF	3006SF	3009SF
	0.33	3303SF	3306SF	3309SF
	0.35	3503SF	3506SF	3509SF
	0.37	3703SF	3706SF	3709SF

5.3 Experimental Findings

Mixes were prepared and test performed according to procedures described earlier. Table 20 provides the details of the rheological properties observed for concrete mixes with silica fumes. Figure 17-21 below show the effect of silica fume on various rheological and harden concrete properties. From the rheological point of view, a silica fume content of 6% should be recommended. Modulus of elasticity was observed to reduce with increase in silica fume content. The 28-day strength chart is very intriguing. The compressive strength of SCC mix prepared showed a distinct U-shape curve with respect to w/cm ratio. This could be perhaps explained by the fact that at higher w/cm ratio, the concrete is more workable and assumes a denser configuration. This phenomenon needs to be further studied.

Table 20. Rheological Properties of the SCC Mixes with Silica Fume.

Mix ID	VMA (ml)	HR WR (ml)	Air (%)	Unit Weight (lb/ft^3)	Slump Time T-50		Slump Spread		U-Box	L-Box			V-Funn.
					Reg. (s)	Invert (s)	Reg (in)	Invert (in)	I_U	T-20 (s)	T-40 (s)	I_L	(s)
3003SF	191	300	2.5	145.38	7	7	27.16	27.44	0.977	4	10	0.977	41
3006SF	150	243	3	146.28	7	6	27.16	27.16	0.896	6	26	0.714	37
3009SF	150	356	2.5	146.50	4	4	27.56	28.74	0.941	4	28	0.540	17
3303SF	56	206	5	139.94	3	3	30.11	29.13	1.0	2	5	0.938	5
3306SF	63	186	6.5	140.26	3	3	28.35	27.56	0.968	4	14	0.682	30
3309SF	56	150	2.5	141.90	4	2	29.92	28.34	1.0	2	6	0.938	7
3503SF	38	169	5.5	138.18	5	5	26.38	25.19	1.0	2	4	1.0	6
3506SF	42	169	5.5	139.5	2	3	26.77	27.16	1.0	2	6	0.632	21
3509SF	94	225	8.5	128.95	3	3	29.13	27.95	1.0	1	5	0.769	10
3703SF	38	75	4	141.52	2	2	27.16	25.59	1.0	1	4	0.778	7
3706SF	38	131	7	135.50	2	2	29.52	28.34	1.0	1	2	1.0	5
3709SF	56	75	5	139.72	2.5	2	25.19	24.80	0.914	1	3	0.778	6

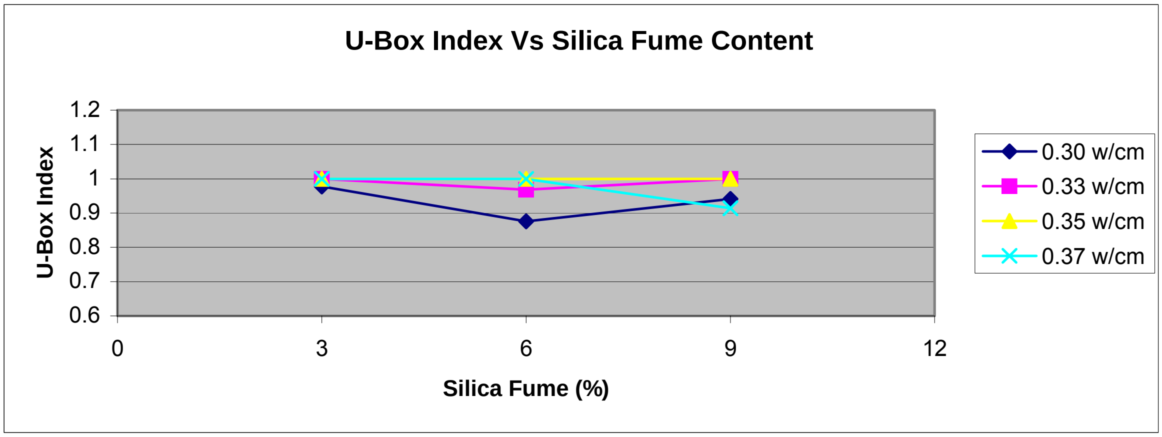


Figure 16. Effect of Silica Fume on U-Box Index

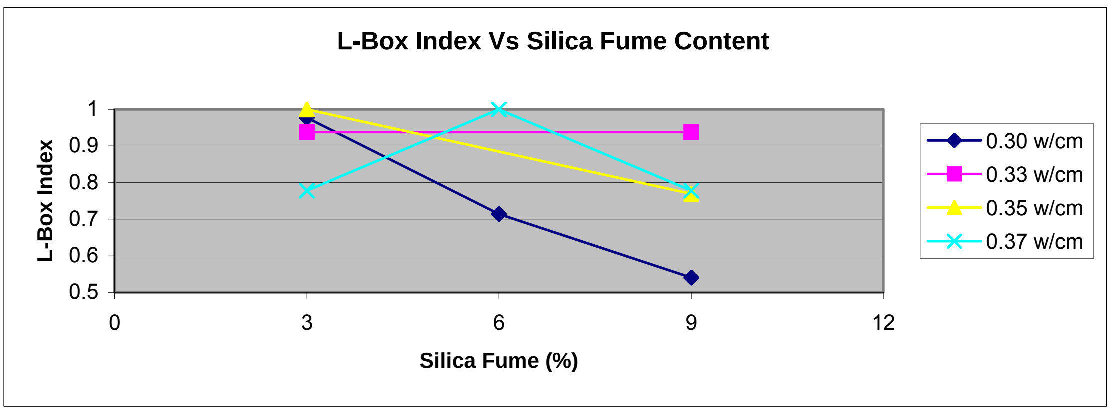


Figure 17. Effect of Silica Fume on L-Box Index.

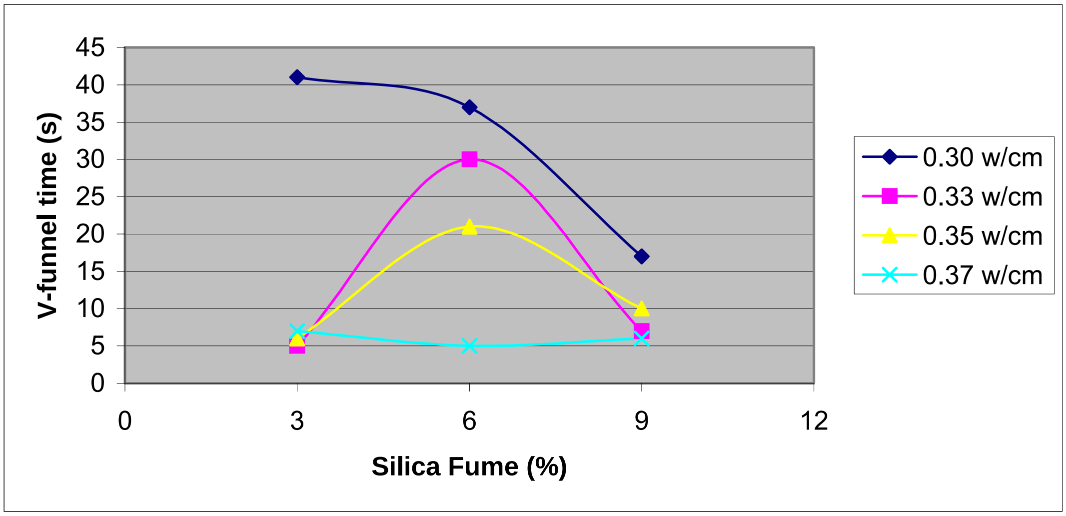


Figure 18. Effect of Silica Fume on V-Funnel Index.

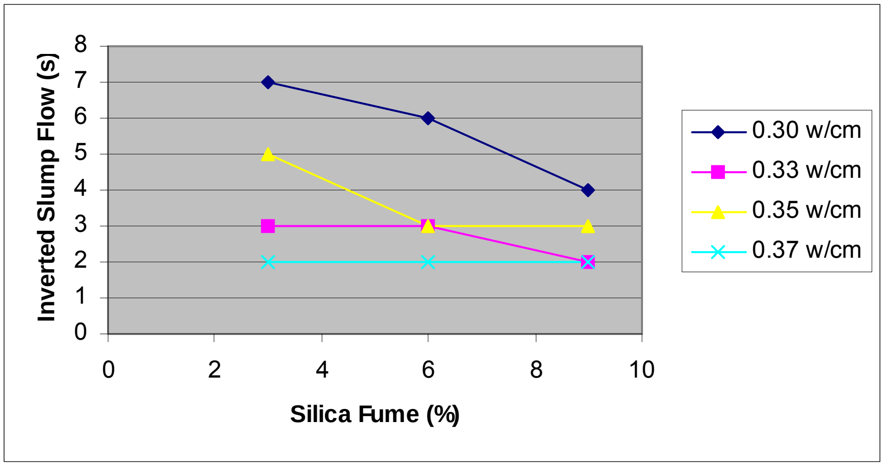


Figure 19. Effect of Silica Fume on Inverted Slump Flow.

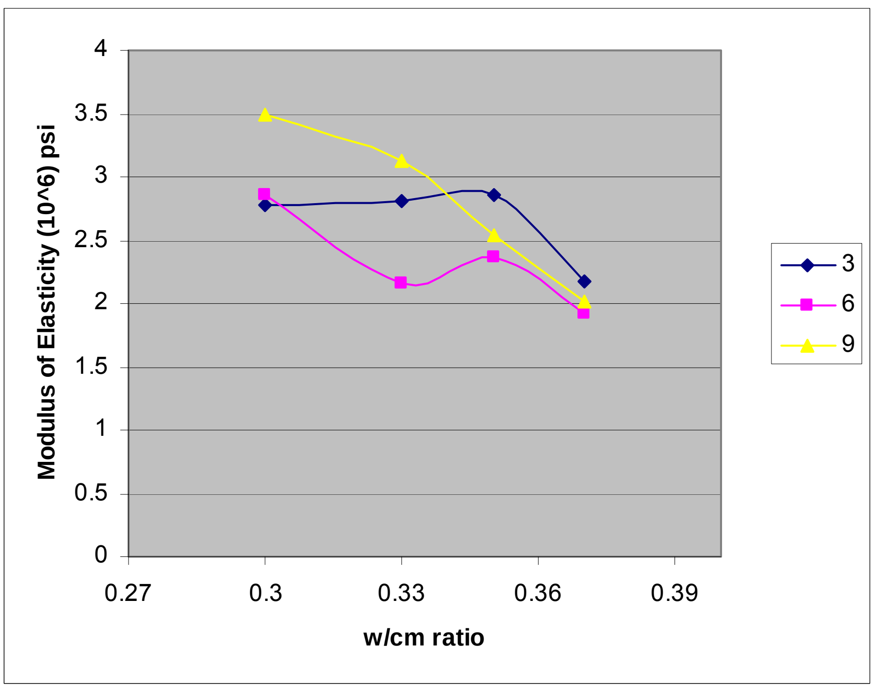


Figure 20. Effect of Silica Fume on Modulus of Elasticity.

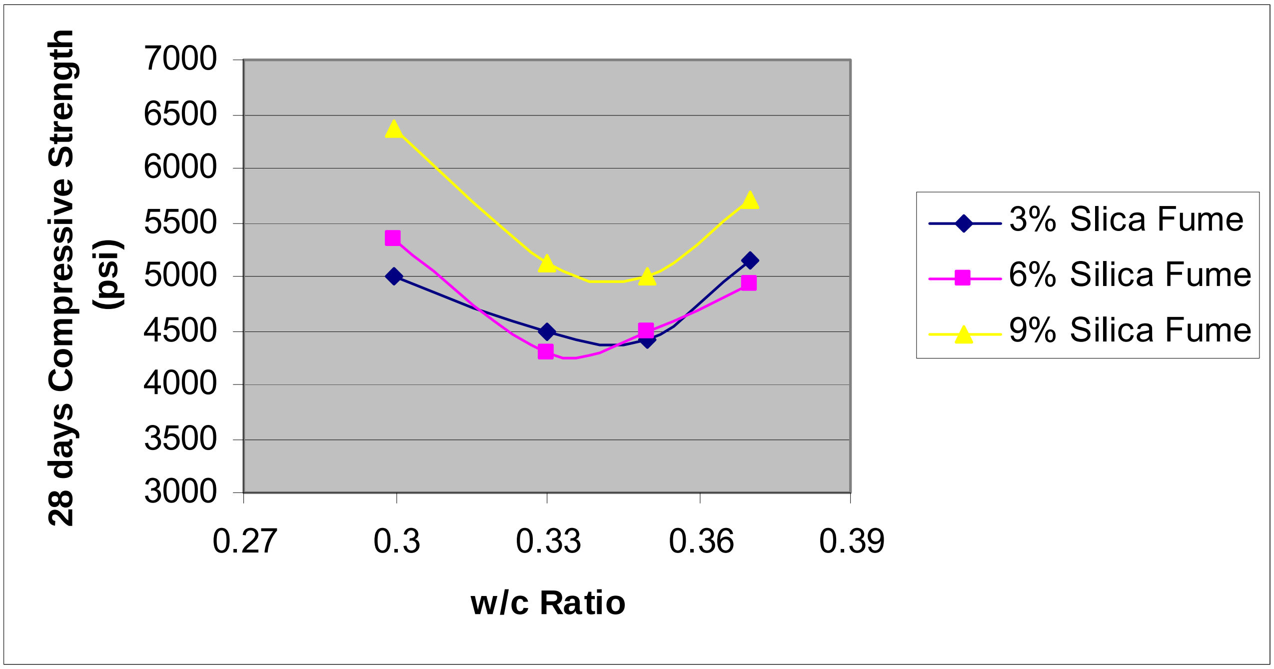


Figure 21. Effect of Silica Fume on 28-day Compressive Strength.

CHAPTER 6

INFLUENCE OF GROUND GRANULATED BLAST FURNACE SLAG

6.1 Introduction

Blast Furnace Slag is quickly quenched by water or air to produce Granulated Blast Furnace Slag. When ground to cement fineness, ground granulated blast furnace slag (GGBFS) has been used extensively as a Portland cement replacement in concrete.

Using slag cement to replace a portion of the Portland cement in a concrete mixture is a useful method to make concrete better and more consistent. Among the measurable improvements are:

- Better concrete workability
- Easier finishability
- Higher compressive and flexural strengths
- Lower permeability
- Improved resistance to aggressive chemicals
- More consistent plastic and hardened properties
- Lighter color

In concrete, slag cement is normally proportioned from 20 to 80 percent depending on the application. In this study, GGBFS was substituted for Portland cement on a one-to-one basis by mass.

6.2 Experimental Factorial

In order to measure the influence of Fly Ash with GGBFS, the experimental matrix shown in Table 21 below was carried out. Here, three levels of Fly Ash (0, 10 and 25%) and three levels of GGBFS (25, 40 and 60%) were used for concrete with w/c ratio of 0.37 and cement content of 900 lb/yd^3.

Table 21. Experimental Matrix to Study Effectiveness of Fly Ash and Slag in SCC.

Cementitious Content →		**900 lb/yd^3**		
Fly Ash		**0%**	**10%**	**25%**
Slag	25%	3725SL00	3725SL10	3725SL25
	40%	3740SL00	3740SL10	3740SL25
	60%	3760SL00	3760SL10	3760SL25

6.3 Experimental Findings

The rheological test results as shown in Table 22 indicated that presence of fly ash is necessary to achieve and/or improve SCC attributes in the concrete with GGBFS. Figure 22-25 show the effect of fly ash in combination with slag. It is clearly seen from the fresh concrete properties that the some presence of fly ash is necessary to produce SCC. Generally, the mixes show improved properties up to 10% fly ash and then deteriorated with increased fly ash. Hence, it was recommended that 10 % fly ash be used with slag. For the further investigation of GGBFS, a constant 10% Fly ash was used to study effect of changing w/cm ratio as shown in the experimental matrix in Table 23.

Table 24 shows the experimental setup to study the effect of w/cm ratio and different levels of slag on SCC mixes. SCC mixes were successfully prepared for all w/cm ratio ranging from 0.30 to 0.37, although it required high dosage of admixtures at lower w/cm ratio and had larger V-funnel time.

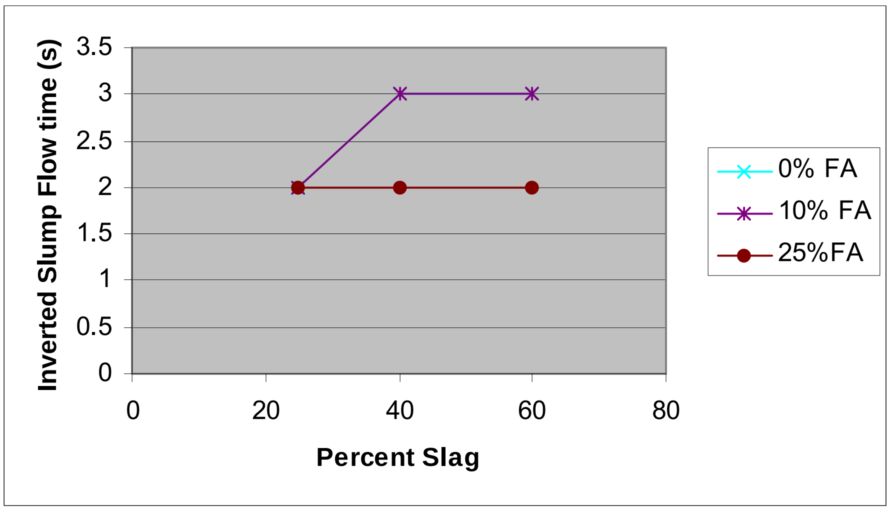


Figure 22. Effect of Fly Ash on GGBFS SCC's Inverted Slump Flow.

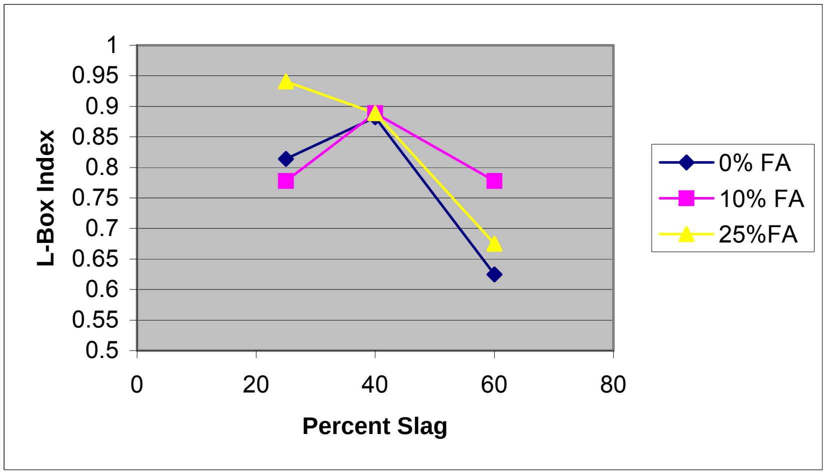


Figure 23. Effect of Fly Ash on GGBFS SCC's L-Box Index.

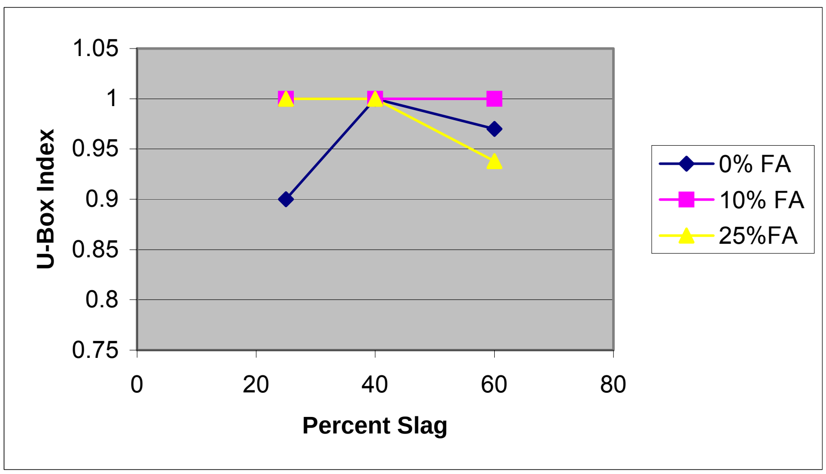


Figure 24. Effect of Fly Ash on GGBFS SCC's U-Box Index.

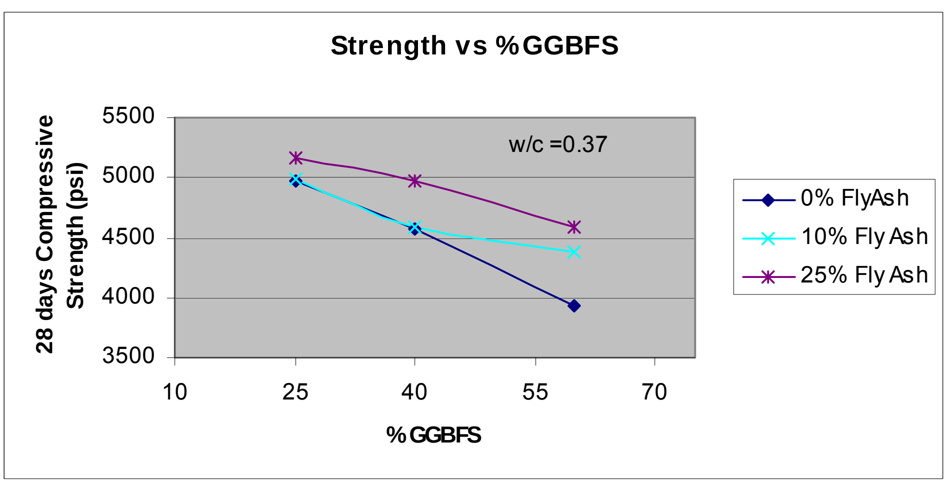


Figure 25. Effect of Fly Ash on GGBFS SCC's 28-day Compressive Strength.

Table 22 The Effect of Fly Ash on GGBFS Concrete.

Mix ID	VMA (ml)	HR WR (ml)	Air (%)	Density (lb/ft^3)	Slump Time T-50 Reg. (s)	Slump Time T-50 Invert (s)	Slump Spread Reg (in)	Slump Spread Invert (in)	I_U	L-Box T-20 (s)	L-Box T-40 (s)	L-Box I_L	V-Funn. (s)
3725SL00	38	150	10	132.08	4	2	29.13	29.95	0.9	2	5	0.814	8
3740SL00	38	146	8	133.72	3	3	27.16	23.37	1.0	2	5	0.882	7
3760SL00	38	150	3	143.08	4	3	28.74	24.80	0.97	3	8	0.625	14
3725SL10	56	94	7	136.90	2	2	29.13	26.77	1.0	2	4	0.778	12
3740SL10	38	112	2.5	145.38	3	3	29.58	23.22	1.0	2	3	0.889	4
3760SL10	56	112	9	133.76	3	3	26.77	25.69	1.0	1	3	0.778	7
3725SL25	56	94	3	144.50	2	2	30.70	20.70	1.0	1	3	0.941	11
3740SL25	56	94	3	142.44	1	2	30.11	29.92	1.0	3	5	0.889	7
3760SL25	38	38	2.5	142.04	3	2	28.74	26.38	0.94	2	6	0.675	11

Table 23. Experimental Matrix to Study Effect of GGBFS with Constant Fly Ash content.

		GGBFS (w/ 10% Fly Ash)		
		25%	40%	60%
.w/cm ratio	0.30	3025SL	30405SL	3060SL
	0.33	3325SL	3340SL	3360SL
	0.35	3525SL	3540SL	3560SL
	0.37	3725SL	3740SL	3760SL

Table 24. The Effects of GGBFS on Constant Fly Ash Concrete.

Mix ID	VMA (ml)	HRWR (ml)	Air (%)	Density (lb/ft^3)	Slump Time		Slump Spread		U-Box	L-Box			V-Funnel (s)
					Reg. (s)	Invert (s)	Reg (in)	Invert (in)	I_U	T-20 (s)	T-40 (s)	I_L	
3025SL	202	422	5	143.46	3	-	28.34	-	0.829	5	13	0.89	45
3040SL	215	316	3.5	145.54	5	3	28.54	26.77	0.97	4	15	0.96	83
3060SL	80	223	4	143.48	3	4	30.31	29.13	1.0	2	6	1.0	27
3325SL	51	200	5	144.8	3	4	28.34	28.74	1.0	3	6	0.86	35
3340SL	42	177	6.5	140.32	4	6	27.95	26.77	0.936	5	15	0.698	40
3360SL	42	223	4	143.98	2	4	30.70	29.52	1.0	4	11	0.721	35
3525SL	42	169	4.5	137.74	2	4	29.53	29.13	1.0	2	4	0.75	14
3540SL	42	84	2.0	140.07	1	2	26.77	25.98	0.806	2	5	0.71	17
3560SL	42	194	5.5	139.96	4	3	22.44	26.38	1.0	4	17	0.60	7
3725SL	56	94	7	136.90	2	2	26.77	26.77	1.0	2	4	0.778	12
3740SL	38	112	2.5	145.38	3	3	23.22	23.22	1.0	2	3	0.889	4
3760SL	56	112	9	133.76	3	3	25.69	25.69	1.0	1	3	0.778	7

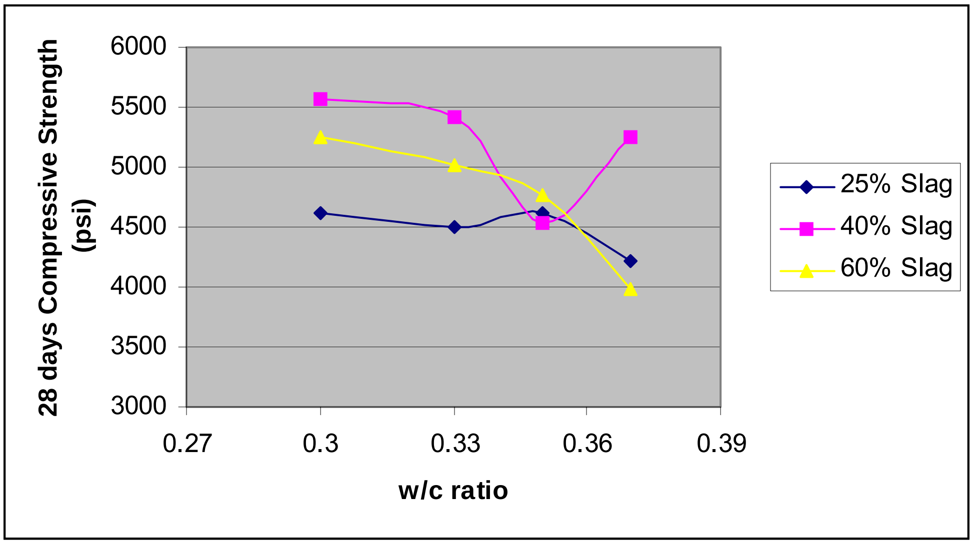


Figure 26. Effect of w/cm ratio and slag percent on 28-day Compressive Strength.

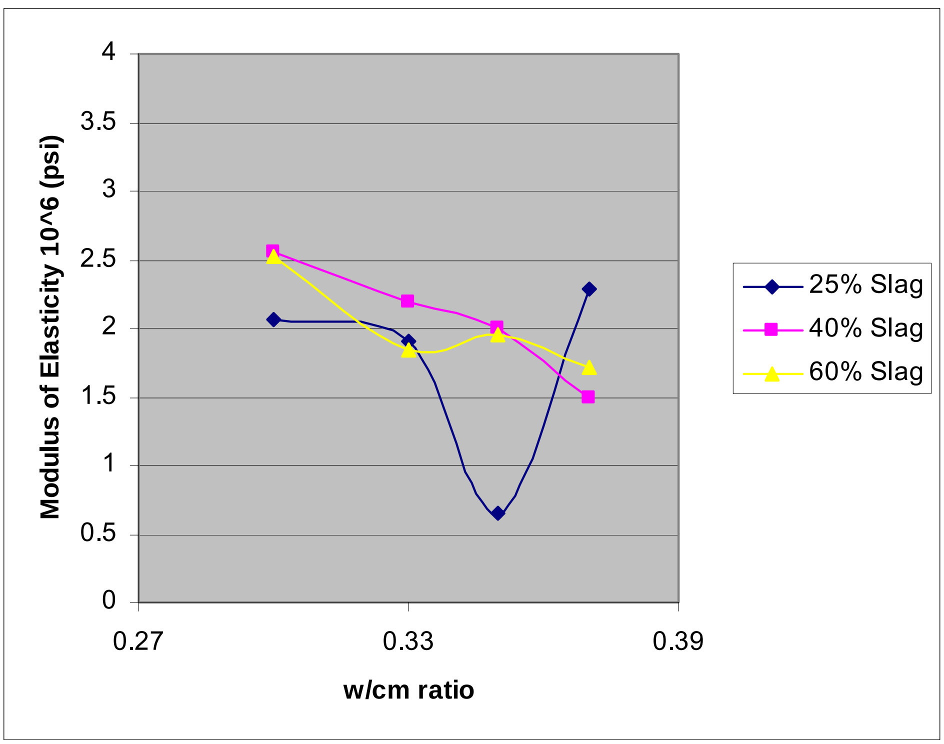


Figure 27. Effect of w/cm ratio and slag percent on Elastic Modulus of Concrete.

Figure 26 illustrates the effect of w/cm ratio and percent slag replacement on 28-day compressive strength. As evidenced in the figure, 40% dosage generally provided better strength than 25% or 60% replacement. Also, from Figure 27, one can observe the influence of slag dosage on elastic modulus. Again, the modulus decreased with w/cm ratio and 40% replacement showed better modulus. Generally, it was observed that the modulus of concrete with slag was lower at 28 days than conventional concrete at the same age. With above observations, it is clearly seen that for SCC, a slag-cement substitution should be limited to approximately 40% for optimal performance.

CHAPTER 7

ECONOMIC IMPACT AND BENEFITS OF SCC

7.1 Introduction

There is no easy answer to questions about the economic benefits of SCC. There are factors that cannot be easily quantified in dollar amount but nonetheless the benefits of SCC cannot be overlooked. A material and cost difference exists from one location to other. Depending upon the application for example structural or architectural, performance requirement can be significantly different and alter the cost. For example, an architectural wall panel producer may focus more on ease of placement and the finished aesthetics of the precast product, while a structural precast producer may focus at the labor savings during the pouring and patching process.

As a general rule [25], a contractor should expect to pay 20 percent to 40 percent more for SCC than for conventional concrete. Costs for SCC for small and extremely difficult jobs are expected to be higher. However, the labor savings a contractor will realize should more than make up the difference in material costs. For example [25], a 49'x10' wall that will be 6 inches thick requires 9 cubic yards of concrete. If a $20 per cubic yard premium is assumed for the SCC, the contractor's upfront cost is increased by $180. However, eliminating a laborer operating a vibrator will save at least $60 (not accounting for equipment or power costs). And since the job will not require rubbing and patching, another $170 to $200 will be saved (assuming a cost of $0.35 per square foot for 490 square feet). The total labor savings more than offsets the initial concrete cost difference. Other benefit includes quieter, safer job site and a better end product. Using the flowable properties of SCC, the contractor may be able to flow the concrete straight from the truck and eliminate the need for additional heavy equipment, thus realizing additional savings. Other benefit of SCC include lesser wear and tear on the equipment, reduce patching and touchups.

For the producers, the ability to discharge and place concrete faster may imply increased throughput and the corresponding ability to service more jobs. Additionally the less wear and tear on the truck and plant mixing equipment because of SCC's high fluidity may increase the serviceable life of these fixed assets. Producers can also use this new technology to gain edge over their competitors and increase profitability to their operations.

When analyzing the economic impact of SCC in a precast environment, it is easier to break the topic into three main categories as follows:

- Concrete Mix Design and Raw Material Options
- Production Cost Efficiencies
- Finished Product Improvements

7.2 Economics of Concrete Mix Design And Raw Material Options

As noted earlier, to achieve these SCC properties, higher cement content and increased number and dosage chemical admixtures is needed. A cement content increase from 658 to 800 pounds per cubic yard will result in an average cost of $80 per ton which will result in increased cement cost of $3.00 - $6.00 per cubic yard [26]. Admixture costs can vary depending on dosage and effectiveness, but typically, the premium for a newer generation HRWR admixture in a SCC mixture would be between $2.00 and $2.50 per cubic yard. Use of rounded aggregates such as river rock and higher sand content could also result in an increases cost of production. Use of pozzolanic materials such as fly ash to replace a part of cement in the mixture can result in significant cost savings. Due its fine nature, fly ash also imparts improved flowability and stability of the SCC mixture.

Table 25 [[26]] highlights the costs associated with a SCC mixture with a slump flow of 27 in. (685 mm) versus that of a traditional 6-8 in. (150 to 200 mm) slump mixture proportioned for a structural double-tee application. The cost/yd3 information was calculated using an actual precast structural mix design, but using cost data taken from ENR Construction Economic Data for Cleveland published on August 5, 2002.

Table 25. Costs Comparison of a 27-in SCC Mixture with Conventional Concrete Mix.

	Cost/yd^3		
Ingredient	Conventional Concrete	SCC Mixture	SCC mixture w/ Fly ash
Cement	$24.10	$27.65	$21.73
Fly Ash			$3.00
Coarse Aggregate	$7.49	$6.28	$6.16
Fine Aggregate	$4.31	$4.46	$4.38
Traditional Admixtures	$3.14	$0.19	$0.19
NG HRWRA		$6.70	$6.70
VMA		$0.44	$0.44
TOTAL	**$39.04**	**$45.72**	**$42.60**

In this application, there was a \$6.68/yd^3 premium in raw material costs for a SCC mixture that would have comparable engineering performance properties relative to those of a traditional 6 - 8 in. slump concrete mixture. With the use fly ash, the premium for the SCC mix was reduced to \$3.56/yd^3. Hence, there will always be a raw material cost premium for producing SCC mixture but the savings at a precast plant will be achieved in the form of production cost efficiencies.

7.3 Economics of Production Cost Efficiencies

The production efficiencies associated with the use of SCC include factors such as

- pouring time
- vibration use and maintenance
- form maintenance and longevity
- heating costs for curing
- worker safety

Pouring time is the time it takes to transfer the concrete from the mixing unit, then place and consolidate the concrete into the precast mold. Typically, use of SCC reduces the pouring time by about 20%-30%. Personnel not required for the pour can thus be moved to assist in other parts of production plant. The freed-up workers can be used to set up more forms to be poured during the day, thereby producing more precast pieces, and to load trucks for faster turnaround in completing projects. Additionally, savings will also be achieved in terms of reduced vibratory equipment and their maintenance cost. A typical investment in time and maintenance employed for using vibratory equipment generally vary from \$0.50 per cubic yard for structural elements to $1 per cubic yard for architectural element. The formwork will also experience less wear and tear. The implementation of a SCC program could also result in reduction or even complete elimination of steam curing resulting in a significant savings. Finally, the elimination of vibrators will reduce noise levels, reducing the amount of headaches and eliminating the need for hearing protection. Since SCC will also eliminate need for the workers to be in an awkward position as experience during a conventional pouring, it should result in fewer accidents. An overall improvement in worker safety and potentially a reduction in lost time accidents may result in a reduction in workers compensation premiums.

7.4 Economics of Finished Product Improvements

Over the years, SCC has been clearly proven to reduce the number of bugholes, honeycombing, and other surface imperfections on the finished concrete surface. A SCC may also minimize the number of pieces scrapped due to poor consolidation. The costs associated with patching materials are also reduced. With improved finish and looks, producer can also market their product more effectively and gain edge over the competition.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

Following conclusions and recommendation are made Based on the result of study conducted:

1. SCC usage is on the rise and its usage will become routine in near future.
2. SCC mixes are best achieved for sand/aggregate ratio (S/A) of 0.5 to 0.55
3. Based on the factorial study and with existing admixtures developed for SCC and their recommended maximum dosage limits, it is also recommended that a minimum cementitious content of 825 lb/yd^3 should be used for w/c ratio below 0.37 and a minimum cementitious content of 900 lb/yd^3 for w/c below 0.33.
4. Fly ash substitution generally results in favorable outcomes and is highly recommended for all SCC mixes.
5. A 20% replacement of cement with fly ash resulted in consistently better VSI rating for the mixes studied.
6. For w/c ratio below 0.33 and cement content below 825 lb/yd^3, higher dosage of fly ash (up to 50%) should be investigated.
7. Rheological tests chosen and performed were sufficient to ascertain whether the mix will have all the attributes of SCC or not, i.e., the fresh concrete test used were sufficient to measure the filling ability and passing ability.
8. It is recommended that, at the minimum, Slump test, U-Box and L-box should be performed for the laboratory verification tests.

9. If a concrete mix self-levels in a U-box (U-box index =1), it will generally pass all other tests. This is due to fact that in the U-box the concrete has to move against gravity versus flowing horizontally in the L-box.
10. Stability and segregation resistance of SCC mixes needs further study and VSI rating may not be enough to distinguish a segregating concrete. VSI is subjective and hence prone to error.
11. Spread test using inverted cone generally resulted in similar result as in regular testing (upright cone).
12. Segregation resistance testing may need further development of a test system.
13. Silica fume is a viable secondary cementitious material. It leads to higher than usual modulus value and from the mixes studied, it is suggested that no more than 6% silica be replaced by mass. These changes will require a change in the specifications.
14. Ground Granulated Blast Furnace Slag (GGBFS) was also tested at various levels and was also found to be a viable secondary cementitious material. Form the test and result obtained, it is suggested that no more than 40% slag be replaced by mass in SCC. In addition, presence of fly ash was found necessary to achieve the a good SCC mix. It is suggested that a minimum of 10% fly ash be recommended with slag usage.
15. Because the technology for making self-consolidating concrete is mostly in the hands of the ready-mix producer and because of local variations in

properties of available materials, the best approach is to use a performance-based specification instead of specifying the specifics of the mix design.

16. The economic impact of switching to using SCC should be analyzed at the plant. Trial batches should be performed in close relationship with the admixture supplier to identify the exact combination of admixtures and other concreting materials needed to optimize the element, in terms of both engineering performance and cost efficiency. It is well documented that the increase in raw material costs are easily offset with improvements in pouring productivity and reductions in vibrator cost and maintenance.
17. Other benefits of switching to SCC program include safety improvements, elimination of steam curing, patching cost reductions, and improved form. When implemented correctly, the incorporation of SCC in a precast operation should minimize the overall costs of producing each piece.
18. SCC is recommended for use in transportation structures that can benefit from concretes with high workability, particularly in thin sections and areas with dense reinforcement.
19. Forms should be water tight and be able to accommodate full hydraulic pressure.
20. Forms should be level (unless designed for specific sloped/curved applications).
21. Coordinate batching speed with placement speed.
22. Use of large discharge equipment allows further flowing capability.
23. Let SCC flow into formwork horizontally and avoid direct free-fall.

CHAPTER 9

GUIDELINES AND INTERIM SPECIFICATION FOR SCC USING FLORIDA MATERIALS

9.1 Introduction

With the increased usage and popularity of self-consolidating concrete (SCC), a need for guidelines and specification for designing and producing SCC has become necessary. In recent past, various entities have attempted to develop such standards and guidelines. Following are the references to Standards and Guidelines either established and under development:

- American Concrete Institute (www.aci-int.org) Subcommittee 236B, formed in 2002, is preparing a state-of-the-art report on SCC.
- American Society for Testing and Materials (www.astm.org) Subcommittee C09.47 on Self-Consolidating Concrete, formed in 2002 to develop a standard for SCC in the U.S.
- Brite-EuRam project BRPR-CT96-0366, Rational Production and Improved Working Environment Through Using Self Compacting Concrete, Guidelines (2000). BRITE (Basic Research in Industrial Technologies for Europe)-EuRam is a cooperative research program under the European Commission.
- EFNAR guidelines, "Specification and Guidelines for Self-Compacting Concrete," EFNAR is a European member organization providing support in the implementation of the new European Specifications and Regulations.

- Japan Society of Civil Engineers Concrete Committee, “Recommendation for Self-Compacting Concrete” (1998). English translation available on CD.
- National Cooperative Highway Research Program, Transportation Research Board, Project 20-30, NCHRPIDEA 89: “US-Specific Self-Compacting Concrete for Bridges.” Project Manager**,** Jencks, Crawford F. The final report will provide recommended specifications and guidelines for the design and sue of self-compacting concrete for highway structures in the U.S.
- Precast/Prestressed Concrete Institute (www.pci.org) guidelines for the use of SCC in precast/prestressed applications, 2003.
- RILEM Technical Committee 188-CSC: Casting of Self-Compacting Concrete, formed Sept. 2000. Chair, Prof. Skarendahl (Sweden).

Upon conclusion of this research project and studying the literature, it is clear that, at the present time, with no standard test adopted by ASTM or DOT, it would be impossible to come up with any definite or specific of mix design for a given class of concrete. The best approach is to use a performance-based specification. However, guidelines and experience gained during the execution of this project can be used and shared to improve success of SCC usage for the FDOT use. It is the author opinion that the interim guidelines as suggested by PCI can be adopted for the DoT usage with particular attention to conclusions and recommendations for the Florida materials. It is expected that in near future, a consensus on the tests, testing equipment and methods would be reached allowing a uniform usage of SCC.

9.2 Definitions and Abbreviations

SCC – Self-consolidating Concrete, also known as Self-Compacting Concrete

VMA- Viscosity modifying admixtures

S/A = Sand to total aggregate ratio by volume

VSI = Visual Stability Index

L-box Ratio (I_L) = Ratio of height of concrete at 20cm and 40cm mark

U-box Ratio (I_U)=Ratio of concrete height in the two arms of U-box

9.3 Specifications and Guidelines

Following specification for SCC is recommended.

9.3.1 Mix Design

Produce SCC in accordance to PCI interim guidelines (TR-6-03) in the laboratory trial batch. Evaluate the test equipment and local materials used in the plant to determine the correct mixing sequence and mixing times.

9.3.2 Mix Design Process

Trial mix design process is similar to the ACI concrete mix proportioning guideline expect for the adjustment made to sand to total aggregate content as described earlier in the report. The Maximum allowable S/A ratio is recommended at 55%. The minimum S/A ratio is recommended at 50%. VMA dosage will increase with lower S/A ratio. In general, SCC mix will require:

- High volume of paste to maintain aggregate separation

- High volume of fine particles to reduce risk of segregation or bleeding
- High dosage of HRWR to give fluidity
- Use of VMA for lower S/A ratio or higher w/c ratio
- Low coarse aggregate content and smaller maximum aggregate size to improve its passing ability.

Due typical higher cement content, a fraction of Portland cement is generally replaced by supplemental cementitious materials. Mineral admixture such as fly ash, GGBFS, silica fume has been traditionally used in concrete. It is highly recommended to substitute at least 10% of cement with flyash and possibly more for mixes with water cement ratio below 0.33. If slag is to be used, it must be limited to 40% and silica fume must be limited to 6% substitution. To accommodate these recommendations, specifications will need to be changed.

9.3.3 Minimum Requirements

The most important aspect of SCC is its properties in fresh state and is designed to flowable with external vibrations and processes passing and filling ability. To measure these properties, slump-flow test, L-box test and V-funnel test are recommended and must be performed for laboratory verification. U-box may also be performed to evaluate the passing ability.

During the slump-flow test, concrete is placed in the standard slump cone and time to spread 50cm and final diameter is measured. The actual spread requirement should depend on the project and element details but must not be less then 60cm.

Concrete with VSI rating of 2 or more must be rejected. Concrete with VSI of 1.5 or more will clearly show the halo of mortar at the periphery of the spread concrete indicating segregation potential.

The L-box index as defined as ratio of concrete height at 20cm and 40cm mark must not be less than 0.80. An index value of 1.0 indicates a desirable self-leveling condition. Similarly, U-box index of 0.8 or more is recommended. U-box index is ratio of concrete heights on each arm after the concrete is allowed to flow through the obstructions.

V-funnel test ability of concrete to flow through small openings and must be less then 15 seconds. In addition to above mention tests, perform air-content, unit weight, temperature and bleed test.

9.3.4 Mixing of Concrete

All common mixers can be used to produce SCC. Mixing times are typically longer compared to conventional concrete. The sequence of adding material and mixing time will depend on the available equipment and hence the producer will have to determine the most effective and suitable method based on the laboratory trial batch and field demonstration.

Due to SCC sensitivity to water content, moisture content of the aggregates must be measured to an accuracy of ±0.5%.

9.3.5 Hardened Concrete Properties

SCC can be easily produced over a wide range of concrete strength. Due to their w/cm ratio and use of higher cement content, specified minimum 28-day strength can be easily met for all classes of concrete as per Florida Specification 346. One of the drawback observed during this project was the high degree of fluctuations in the air content of the fresh concrete. A wider air-content range of 2-8% is suggested as a possible specification

Durability of concrete can be measure in accordance to FM 5-578 (Surface Resistively test). Typically, sample with surface resistively of 37 KOhms-cm indicates very low chloride ion permeability.

9.3.6 Transportation and Placement of SCC

Transportation of SCC is an important element and proper training must be provided to all who will handle the concrete. Concrete should be continuously agitated to prevent any occurrence of segregation by first rotating the drum at low speed while waiting and then at full speed just before the delivery for 3 minutes.

Concrete shall be checked according to approved QC program before delivery and in general accordance to Florida specification 346.

SCC can be safely placed by pump, skip or chute. When pumping, a better finish has been observed when concrete is placed from below or by placing the nozzle of the concreting pipe below the concrete surface and gradually lifting it during placement.

Although SCC can maintain its integrity even with free fall of 10ft and higher, care should be taken to avoid excessive free falls. When placing large amount of SCC, pre-placed concreting pipes for the easy distribution should be used. Slump flow of SCC for large slabs can be lowered to prevent runaway condition or limit the area of spread.

9.3.7 Formwork

Special attention to water-tightness of the formwork must be addressed to prevent loss of cement paste. Many studies have shown that the there is no increased form pressures due to SCC and normal formwork can be used as long as no paste is lost to leakage. Formwork must conform to Section 450 of Florida specification for formwork and finishing requirements.

9.3.8 Test Methods

For conventional test procedures and properties, refer to Section 346, Table 5 for the Florida DOT specifications. For measuring properties specific to SCC, following are the corresponding reference to PCI interim guideline (PCI-TR-6):

- Slump flow and VSI – Appendix A2.0
- L-Box- Appendix A8.0
- V-funnel – Appendix A7.0
- J-Ring – Appendix A6.0
- Surface Resistively – FM 5-578

FDOT currently uses aggregate segregation “Aggregate Segregation Test Method” that was presented in 2003 PCI Symposium by Ghulam Mujtaba and Buhler.

9.3.9 Performance Requirements of SCC

Performance requirement of SCC are complex and governed by many factors. The critical performance factor for SCC obviously is related to its fresh state and include

- Filling ability
- Stability during handling and placing
- Resistance to segregation and bleeding
- Homogenous quality

Unlike conventional concrete where w/cm ratio is mainly controlled by strength and durability requirements, in SCC further adjustments to w/c ratio may be required to achieve the flowability and self-consolidation. Hence, it is very important to first develop proper and appropriate specifications for a given structure or element being built. Due to increased fine material and higher cement content in SCC, due care should also be given to hardened concrete properties such as creep, shrinkage and modulus of elasticity. Required fluidity of the concrete will also depend on the element type and reinforcement level present. A more intricate or densely reinforced element would require higher flowability and passing ability. Another important factor to consider is the compatibility of the various admixtures typically used in the production of SCC. It is not unusual to see use of various pozzolanic materials such as flyash, slag, silica fume along with chemical admixtures such as HRWR, VMA and AEAs in the production of SCC. Concrete producer must make sure the compatibility and limitation of these admixtures for each project.

APPENDIX

DATA SHEETS OF VARIOUS SCC ADMIXTURES

GRACE CHEMICALS - ADVA 360

AXIM CONCRETE - SUPERFLUX 2000PC

SIKA –VISCOCRETE 5000

MASTERBUILDERS – GLENIUM 3000 NS

EUCLID CHEMICALS – VISCTROL

EUCILD CHEMICALS – PLASTOL 5000

Concrete

PRODUCT INFORMATION

ADVA® 360

Superplasticizer for Self Consolidating Concrete

Description

ADVA® 360 is a high efficiency polycarboxylate-based superplasticizer. ADVA 360 has been formulated to impart extreme workability without segregation to concrete, and to achieve high early compressive strength. ADVA 360 is intended for the production of Self Consolidating Concrete (SCC) in ready-mix applications. ADVA 360 is formulated to comply with ASTM C 494 as a Type F admixture and ASTM C 1017 (admixture for flowing concrete).

Product Advantages

- Facilitates production of SCC
- Provides concrete stability
- Reduces segregation
- Provides mix flexibility
- Intended for ready mix applications
- Neutral set characteristics

- ADVA 360 is ideal for use in applications where concrete needs to achieve high early strength along with high levels of workability.
- **No Segregation:** SCC is a flowable yet highly cohesive material that will not segregate, and has significantly reduced bleeding.

[redacted]

- Achievement of complete consolidation throughout concrete elements, even in highly reinforced sections
- Increased placement flexibility by enabling use of form geometry and form orientations where the use of conventional concrete mixes would be difficult or impossible

Dosage Rates

ADVA 360 is an easy to dispense liquid admixture. Dosage rates can be adjusted to meet a wide spectrum of concrete performance requirements. Addition rates for ADVA 360 can vary with the type of application, but will normally range from 200 to 780 mL/100 kg (3 to 12 fl oz/100 lbs) of cement. Should conditions require using more than the recommended addition rate, please consult your Grace Representative.

The production of Self-Consolidating Concrete typically requires both the use of specialty admixtures specifically tailored for SCC as well as mix design adjustments. Therefore, for SCC applications, pre-placement testing is strongly recommended to determine the optimal admixture addition rate and appropriate mix design parameters. Factors that influence optimum addition rate include other concrete mix components, aggregate gradations, form geometry, and reinforcement configurations. V-MAR® 3 may be used with ADVA 360 to further modify the rheological properties of SCC Concrete. Please consult your local Grace Construction Products representative for assistance with developing mix designs for Self Consolidating Concrete.

Compatibility with Other Admixtures

ADVA 360 is compatible with all Grace admixtures, including all air entraining agents. Each admixture should be added separately into the mix.

Dispensing Equipment

A complete line of accurate, automatic dispensing equipment is available.

Packaging

ADVA 360 is available in bulk, delivered by metered trucks, in 1041 L (275 gal) totes, and 210 L (55 gal) drums. ADVA 360 will freeze at approximately 0°C (32°F) but will return to full functionality after thawing and thorough mechanical agitation.

Specifications

ADVA 360 is supplied as a ready to use brown liquid. One liter weighs approximately 1.07 kg (one gallon weighs approximately 8.90 lbs). ADVA 360 contains no intentionally added chlorides.

The superplasticizer shall be ADVA 360 as manufactured by Grace Construction Products, Cambridge, MA.

North American Customer Service: 1-877-4AD-MIX1 (1-877-423-6491)

Visit our web site at: www.graceconstruction.com printed on recycled paper

W. R. Grace & Co.-Conn. 62 Whittemore Avenue Cambridge, MA 02140

GRACE Construction Products

Axim
Italcementi Group

CATEXOL™ SUPERFLUX 2000 PC

Admixture for Super-High Strength and Flowable Concrete

Product Description

CATEXOL SUPERFLUX 2000 PC is a new generation superplasticizer based on polycarboxylate technology. This product is designed to provide the highest performance of water reduction, while providing excellent flowability during placement, and excellent slump retention without affecting initial setting time. This product incorporates the latest state of the art technology in high performance concrete.

CATEXOL SUPERFLUX 2000 PC was designed to produce super high-strength concrete, flowable and self-compacting concrete in a variety of applications.

Benefits

- Provides a linear dose response to provide desired water reductions. It is recommended for precast, prestressed and block/paving applications, but can also be used in ready-mix concrete where high strength, self-compacting properties are specified.
- Provides a linear response to allow high levels of water reduction as well as maintaining the level of workability for longer periods of time versus conventional superplasticizers.
- Concrete mixes produced can exhibit a cohesive and non-segrating concrete.
- Can produce lower product costs with the ability to better design the superplasticizer performances to jobsite conditions, including faster and easier placement, enhanced finishability and reduced curing costs.
- More efficient pumping of concrete with pump pressures reduced as much as 50%.
- Reduced discharge and turn-around time for trucks.
- Improves impermeability to reduce sulfate attack.
- Increased productivity, resulting in reduced labor costs.
- Faster reuse of forms.
- Increased strengths at all ages.

Recommendations

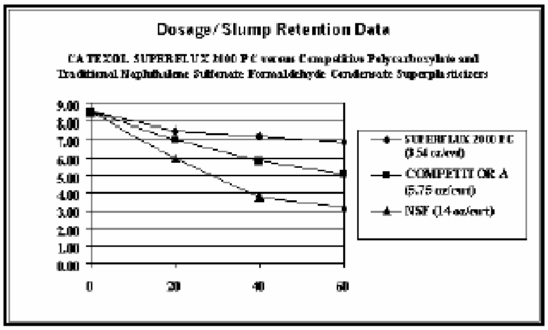
CATEXOL SUPERFLUX 2000 PC is recommended for use in all types of concrete including plain, reinforced, extruded, precast, prestressed, flow-able and self-compacting concrete. **CATEXOL SUPERFLUX 2000 PC** is very effective in concrete containing pozzolanic materials such as fly ash, silica fume and slag.

Dosage

Dosage rates vary depending upon the amount of plasticity and/or water reduction desired. Recommended dosage range for **CATEXOL SUPERFLUX 2000 PC** is 3 to 10 ounces per 100 pounds (200 mls to 650 mls per 100 Kg) of cement for most mix designs. **CATEXOL SUPERFLUX**

An Essroc Company

2000 PC has a linear-dosage response so the dosage amount can be precisely tailored to the degree of water-reduction or slump characteristics required for the application. Because of the variability in cements, field conditions, and other ingredients in the mix, it is highly recommended that trial mixes be prepared to determine the optimum dosage for your specific performance requirements.



Directions For Use

For optimum results, introduce **CATEXOL SUPERFLUX 2000 PC** towards the end of the mixing process. **CATEXOL SUPERFLUX 2000 PC** maintains its superplasticized consistency for up to 90 minutes depending on the dosage and environmental conditions. Factors to consider are ambient temperature, transport distance, and jobsite delays.

CATEXOL SUPERFLUX 2000 PC can be used in conjunction with and is compatible with all of AXIM's non-chloride accelerators.

Applicable Standards

CATEXOL SUPERFLUX 2000 PC meets or exceeds ASTM C-494-98, Types A and F, as well as ASTM C-1017-97.

CATEXOL SUPERFLUX 2000 PC does not contain calcium chloride.

Packaging

CATEXOL SUPERFLUX 2000 PC is supplied in either 55 gallon drums (205 litre) or delivered in bulk.

CATEXOL SUPERFLUX 2000 PC should be kept from freezing. If accidentally frozen, its properties can be restored by thawing and thoroughly re-mixing by mild mechanical agitation.

Technical Service

A trained AXIM representative is available to assist in the preparation of specifications, and the resolution of concrete problems in the field.

Warranty

AXIM warrants its products to be free of manufacturing defects and that they will meet AXIM's current published physical properties when applied in accordance with AXIM's directions and tested in accordance with ASTM and AXIM standards.

AXIM makes no warranty or guarantee, express or implied, including warranties of fitness for a particular purpose or merchantability, respecting its products, and AXIM shall have no other liability with respect thereto. Any claim regarding product defect must be received in writing within one (1) year from the date of shipment. No claim will be considered without such written notice or after the specified time interval.

User shall determine the suitability of the products for the intended use and assume all risks and liability in connection therewith.

Axim
Italcementi Group

AXIM
An Essroc Company
U.S.A.: (800) 899-8795
Canada: (800) 263-6427

Post Office Box 234
8282 Middlebranch Road
Middlebranch, OH 44652
Phone: (330) 966-0444
Fax: (330) 499-9275

141 Shearson Crescent
Cambridge, Ontario NIT 1J3
Phone: (519) 622-5940
Fax: (519) 622-5893

7/01

Sika ViscoCrete® 5000

Sika ViscoCrete® Technology

High Range Water Reducer (Types A & F)

DESCRIPTION

Sika ViscoCrete 5000 is a next generation high range water reducer and superplasticizer utilizing Sika's 'ViscoCrete' technology. It has been formulated to provide maximum water reduction, increased flexibility, and increased early strength.

This unique formulation is based on polycarboxylate polymer technology. It is a non air-entraining admixture that does not affect the air-void system in the concrete matrix in a negative way.

Sika ViscoCrete 5000 does not contain formaldehyde, calcium chloride or any other intentionally added chlorides and will not initiate or promote the corrosion of steel present in the concrete.

Sika ViscoCrete 5000 meets the requirements for ASTMC-494 Types A and F and AASHTO M-194 Types A and F.

APPLICATIONS

Sika ViscoCrete 5000 may be used in both ready mix and precast applications, as a plant added high range water reducer to provide excellent plasticity. Controlled set times make Sika ViscoCrete 5000 ideal for horizontal and vertical slipform applications.

ADVANTAGES

Water Reduction:

Sika ViscoCrete 5000 can be dosed in small amounts to obtain water reduction from 10-15%, and will achieve water reduction up to 45% at high dosage rates.

Sika ViscoCrete 5000 is suitable for all levels of water reduction.

High Plasticity:

The superplasticizing action of Sika ViscoCrete 5000 provides high-slump, flowing concrete that maintains excellent workability and may be placed with minimal vibration even at very low water cement ratio's as low as 0.25.

Sika ViscoCrete 5000 plasticized concrete is highly fluid while maintaining complete cohesion within the concrete matrix to eliminate excessive bleeding or segregation.

BENEFITS

The combined high range water reduction and superplasticizing action of Sika ViscoCrete 5000 provide the following benefits in hardened concrete:

- ▲ Higher early compressive strengths for earlier removal of forms and structural use of concrete.
- ▲ Higher ultimate strengths allow for greater engineering design flexibility and structural economies.
- ▲ Reduced water cement ratios produce more durable, dense concrete with reduced permeability.
- ▲ Highly effective plasticizer reduces surface defects in concrete elements and improves aesthetic appearance.

Combination with other admixtures:

Sika ViscoCrete 5000 is highly effective as single admixture or in combination with other admixtures in the Sika System.

Combination with microsilica:

Sika ViscoCrete 5000 is particularly well suited for use with microsilica because of its water reduction capability and superior slump control.

HOW TO USE

ADDITION RATES

Dosage rates will vary according to materials used, ambient conditions and the requirements of a specific project. Sika recommends dosage at 3-8 fl. oz. per 100 lbs. (195-520 ml./100 kg.) of cementitious for general concrete applications. If maximum water reduction is required dosage up to 16 fl.oz./100 lbs. of cementitious may be used.

Dosage rates outside the recommended range may be used where specialized materials such as microsilica are specified, extreme ambient conditions are encountered or unusual project conditions require special consideration. Please contact your Sika representative for more information and assistance.

MIXING

For best superplasticizing results, add Sika ViscoCrete 5000 directly to freshly mixed concrete in the concrete mixer at the end of the batching cycle.

Sika ViscoCrete 5000 may also be dispensed as an integral material during the regular admixture batching cycle, or into freshly mixed concrete in a Ready-Mix truck at the concrete plant or at the job site.

To optimize the superplasticizing effect after the addition of Sika ViscoCrete 5000, Sika recommends that the combined materials be mixed for 80-100 revolutions or approximately 6 minutes, either in the concrete mixer or in the Ready-Mix truck.

PACKAGING

Sika ViscoCrete 5000 is available in 55 gallon (208 liter) drums and bulk delivery.

STORAGE AND SHELF-LIFE

Sika ViscoCrete 5000 should be stored at above 35°F (2°C). If frozen, thaw and agitate thoroughly to return to normal state.

Shelf life when stored in dry warehouse conditions between 50°F and 80°F (10°C - 27°C) is one year minimum.

CAUTION

Skin and eye irritant; avoid contact. Wear suitable eye, face and hand protection and other protective apparel. For further information, read the current MSDS for this product. Avoid breathing mists. Use with adequate ventilation. Remove contaminated clothing.

FIRST AID

Wash skin with soap and water, in case of eye contact, flush with water for 15 minutes; contact a physician. Wash clothing before re-use.

CLEAN UP

Contain and collect with absorbent material. Dispose of in accordance with local, state and federal regulations.

MASTER BUILDERS

HIGH-RANGE WATER-REDUCING ADMIXTURES

degussa.
Construction Chemicals

GLENIUM® 3000 NS

For the production of high-performance and specialty concrete mixtures

Applications

Recommended for use in:

- Concrete where normal setting characteristics, enhanced surface appearance and accelerated strength development are desired
- Concrete where control of workability and setting time is critical
- Concrete where high-range water reduction (12-40%) is necessary
- Concrete where high-early and ultimate strengths and increased durability are required
- Production of self-compacting and Rheodynamic™ self compacting concrete (SCC) mixtures

Civil and Mining Applications

- Wet/dry shotcrete mixtures
- Grouting
- Cemented backfill
- Mass fill pours in pipes or boreholes

Description

Glenium 3000 NS ready-to-use high-range water-reducing admixture is a patented new generation of admixture based on polycarboxylate chemistry.

Glenium 3000 NS admixture is very effective in producing concretes with different levels of workability including applications that require self-compacting or Rheodynamic SCC.

Rheodynamic SCC is the premier level of self-compacting concrete. It is produced by using a Glenium high-range water-reducing admixture and a Rheomac® VMA viscosity-modifying admixture to provide stability to a concrete mixture.

Glenium 3000 NS admixture meets ASTM C 494 requirements for Type A, water-reducing, and Type F, high-range water-reducing, admixtures.

Features

- Produces cohesive and non-segregating concrete mixtures
- Reduced water content for a given slump
- Linear water reduction throughout the recommended dosage range

Benefits

- Lower production cost due to faster placement, enhanced finishing and reduced curing costs
- Faster setting times and strength development
- Increases compressive strength and flexural strength performance at all ages
- Faster turnover of forms due to accelerated early strength development

Performance Characteristics

MIXTURE DATA

658 lb/yd³ (390 kg/m³) of Type III cement; slump, 6 in. (150 mm); air content, 5-6%; concrete temperature, 65 °F (18 °C); curing temperature, 65 °F (18 °C).

COMPRESSIVE STRENGTH

MIXTURE	8 h psi	8 h MPa	12 h psi	12 h MPa
Conventional Superplasticizer	390	2.7	3090	21.2
Glenium 3000 NS	1230	8.5	4100	28.2

MIXTURE DATA

658 lb/yd³ (390 kg/m³) of Type I cement; slump, 8-9 in. (200-225 mm); non-air-entrained concrete; concrete temperature, 70 °F (21 °C); dosage of admixtures adjusted to obtain 30% water reduction.

SETTING TIME

MIXTURE	INITIAL SET h:min	DIFFERENCE h:min
Plain	3:58	----
Conventional Superplasticizer	7:15	+3:17
Glenium 3000 NS	4:42	+0:44

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

THE EUCLID CHEMICAL COMPANY
19218 REDWOOD ROAD • Cleveland, OH 44110
(216) 531-9222 • (800) 321-7628 • FAX (216) 531-9596
www.euclidchemical.com

VISCTROL

◆ ◆ ◆ ◆ ◆ ◆

VISCOSITY MODIFYING ADMIXTURE

CONSTRUCTION PRODUCTS FOR VOX A SAFER ENVIRONMENT

VISCTROL is a ready to use liquid admixture designed to modify the viscosity of self consolidating concrete. When VISCTROL is used in conjunction with superplasticizing admixtures, 18"-28" (460-710mm) diameter spreads are achieved without segregation or lowering compressive strengths.

PRIMARY APPLICATION

- Self consolidating concrete

FEATURES / BENEFITS

- Greatly reduces or eliminates bleeding or segregation
- Evenly disperses aggregates within mix
- Eliminates need for vibration
- Provides superior slump retention
- Eliminates segregation during pumping
- Easily metered with standard admixture dispensing equipment

APPEARANCE

VISCTROL is a medium viscosity, dark brown liquid which will not discolor concrete.

PACKAGING

VISCTROL is packaged in 275 gallon (1041liter) totes, 55 gallon (208 liter) drums and 5 gallon (18.9 liter) pails.

TECHNICAL INFORMATION

Mix Proportions

See your local Euclid Chemical Company representative

Batching Sequence

The batching sequence in a SCC system is critical to optimize performance of each admixture introduced. Laboratory data has shown the following order of addition to be effective:

1.) Air Entraining Agent (optional)
2.) Water Reducers
3.) Accelerator or Retarder (optional)
4.) VISCTROL

Dosages

Dosages of VISCTROL will vary widely depending on w/c ratio and the gradation of the materials used. Consult your Euclid Chemical representative for appropriate dosing suggestions.

Typically, 1 - 6 oz (39-230 ml/m³) per cubic yard will control bleeding and segregation. Variables such as water/ cement ratio, sand gradations and mix design play an important role. Trial mixes should be run to optimize dosing requirements. With higher water/cement ratios and lower total fines in SCC mixes, dosages of VISCTROL could be as high as 20 oz/yd³(775 ml/m³).

PRECAUTIONS / LIMITATIONS

- Agitate VISCTROL before use
- Do not allow material to freeze
- Air entraining agents must be added first
- Superplasticizers must be used to increase slump after the addition of VISCTROL
- Slight set retardation may occur with the use of this product when dosages exceed 15 oz/yd³ (576 mls/m³).

THE EUCLID CHEMICAL COMPANY
19218 REDWOOD ROAD • Cleveland, OH 44110
(216) 531-9222 • (800) 321-7628 • FAX (216) 531-9596
www.euclidchemical.com

PLASTOL 5000

High Range Water Reducing Admixture

CONSTRUCTION PRODUCTS FOR VOX A SAFER ENVIRONMENT

PLASTOL 5000 is a ready to use polycarboxylate based, high range water-reducing admixture for concrete. PLASTOL 5000 increases early concrete strength as well as ultimate strength. PLASTOL 5000 can be used to produce increased concrete slump or to significantly reduce water demand for a specific slump. PLASTOL 5000 can be added at the plant or jobsite and is compatible with other admixtures. PLASTOL 5000 contains no added chlorides.

PRIMARY APPLICATIONS

- High performance concrete
- Self-consolidating concrete
- Precast concrete
- Low water/cement ratio concrete
- High early strength applications

FEATURES/BENEFITS

- Low water/cement ratio reduces water demand
- Self-consolidating concrete reduces labor costs
- High early strength reduces energy costs
- Controlled setting times reduces labor costs

SPECIFICATIONS/COMPLIANCES

- Fully complies with the requirements of ASTM C-494, Type F admixture and AASHTO M-194 Type F admixture.
- Complies with the requirements of ASTM C-1017 as a Type I admixture

PACKAGING

PLASTOL 5000 is packaged in bulk, 275 gal (1041 liter) totes, 55 gal (208 liter) drums and 5 gal (18.9 liter) pails.

Storage: Agitate before use

Shelf life: 2 years in original, unopened package.

TECHNICAL INFORMATION

Typical Engineering Data

The following results were developed under laboratory conditions.

Compressive Strength PSI (Mpa)

	Control Mix	PLASTOL 5000
1 day	1720 (11.9)	2610 (18)
3 days	3070 (21.2)	4260 (29.4)
7 days	3660 (25.2)	5420 (37.4)
28 days	4640 (32.0)	6200 (42.7)
6 months	5570 (38.4)	7560 (52.1)
1 year	5880 (40.5)	8010 (55.2)

Flexural Strength PSI (Mpa)

	Control Mix	PLASTOL 5000
3 days	475 (3.2)	665 (4.6)
7 days	585 (4.0)	730 (5.0)
28 days	630 (4.3)	790 (5.4)

Time of Set

	Control Mix	PLASTOL 5000
Initial Set	4:49	4:30
Final Set	6:19	5:54

Relative Durability Factor 101.9%

DIRECTIONS FOR USE

Dosage - PLASTOL 5000 can be used at dosage rates of 3 to 15 oz. m(196-978 mls/100 kg) per 100 pounds of cementitious material. Contact your local Euclid Chemical representative for recommendations.

Mixing - After the addition of PLASTOL 5000, the concrete should be mixed for a minimum of five minutes.

Storage and Handling - PLASTOL 5000 should be stored at temperatures above 32°F (0°C). PLASTOL 5000 should be agitated before use.

Compatibility - PLASTOL 5000 can be used with most other concrete admixtures. Contact your Euclid Chemical representative for recommendations.

REFERENCES

[1] ACI, “Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete”, ACI 211.1, ACI Committee Report, American Concrete Institute.

[2] H. Okamura, et al., “High Performance Concrete”, Gihoudou Pub, Tokyo, 1993 (In Japanese).

[3] JRMCA, “Manual of Producing High Fluidity (Self-Compacting) Concrete”, JRMCA, Tokyo, 1998 (In Japanese).

[4] Japanese Society of Civil Engineering, “Guide to Consturction of High Flowing Concrete.’, Gihoudou pub, Tokyo, 1998 (In Japanese).

[5] F. De Larrard, “Concrete Mixture proportioning- A Scientific Approach”, in Modern Concrete Technology Series No. 7, E&FN SPON, 1999, p. 421.

[6] C.L. Hwang, et al, “ Densified Mix design algorithm and early properties of HPC”, J. Chin. Inst. Civil Hydraulic Eng. 8, 1994, 217-219

[7] Nan Su, et. Al, “A Simple Mix Design methods for Self-consolidating concrete”, Cement and Concrete research, Vol 31, 2001, 1799-1807.

[8] Saak, A. W., et al., “New Methodology for Designing Self-Compacting Concrete, ACI Materials Journal, V. 98, No 6, 2001, 429-439.

[9] Su, J. K., et al, “Effect of sand ratio on the elastic modulus of SCC”, Journal of marine Science and technology, Vol. 10, No.1, 8-13, 2002.

[10] Sari, M., et al, “High strength SCC Original solutions associating organic and inorganic admixtures”, Cement and Concrete Research, Vol. 29, 813-818, 1999.

[11] Rapid testing method for segregation resistance of self-compacting concrete, Cement and Concrete Research, Vol. 32, 1489-1496, 2002.

[12] Bauzoubaa N etal, “SCC incorporating high volumes of Class F fly ash, preliminary results”, Cement and Concrete Research, Vol. 31, 413-420, 2001

[13] Ho, D.W.S, et al, “The use fo quarry dust for SCC applications”, Cement and Concrete Research, Vol. 32, 505-511, 2002

[14] Okamura, H., ”Mix Design for Self-Compacting Concrete”, Concrete Library of JSCE, vol. 25, 107-120, 1995.

[15] Petersson, O, Billberg, P., Van, B.K., A Model for Self Compacting Concrete", Proceedings of RILEM, International Conference on Production Methods and Workability of Fresh Concrete, Paisley, Italy, 1996

[16] Sedran, T. and DeLarrard, F., "Mix Design of Self Compacting Concrete", Proceedings of RILEM, International Conference on Production Methods and Workability of Fresh Concrete, Paisley, Italy, 1996

[17] Ouchi, M. et al., "Applications Of Self-Compacting Concrete In Japan, Europe And The United States", 2003 ISHPC

[18] Collepardi, M., "A very Close Precursor of Self-Compacting Concrete (SCC), Symposium on Sustainable Development and Concrete Technology, S. Francisco, 16-19 September 2001

[19] Khayat, K., "Viscosity-Enhancing Admixtures for Cement based materials-An Overview", Cement and Concrete Composites, Vol. 20, 171-188, 1998.

[20] Rixom, R. " The economic Aspects of Admixture Use", Cement and Concrete Composites, Vol. 20, 141-147, 1998.

[21] EFNARC, http://www.efnarc.org/efnarc/SandGforSCC.PDF

[22] Petersson, O., Brite EuRam Contract No. BRPR-CT96-0366, Web site: http://scc.ce.luth.se/

[23] PCA, "Self-Consolidating Concrete: Bibliography of Resources', 2nd Edition, PCA library Bibliography Series No. 6 (LB06.02), 2003.

[24] NIST, "COST User Guide", NIST, FHA, July 2001.

[25] Hill, R., "Self-Consolidating Concrete- A primer for Ready-Mix Applications", CE News, February 2004.

[26] Martin, D., "Economic Impact Of SCC In Precast Applications", First North American Conference on the Design and Use of Self-Consolidating Concrete, November 12-13, 2002