development of high strength concrete with locally available materials

By

Arshad Mahmood

(2004 – NUST – MSc – STR – 10)

A Thesis submitted in partial fulfillment of
the requirements for the degree of
Master of Science

In

Department of Civil Engineering

National Institute of Transportation

National University of Sciences and Technology

Rawalpindi, Pakistan

(2006)

This is to certify that the

thesis entitled

DEVELOPMENT OF HIGH STRENGTH CONCRETE WITH LOCALLY AVAILABLE MATERIALS

Submitted by

Arshad Mahmood

Has been accepted towards the partial fulfillment

of

the requirements

for

Master of Science in Civil Engineering

____

Brigadier Dr. Tayyeb Akram, PhD (USA)

National Institute of Transportation, Risalpur

National University of Sciences and Technology, Rawalpindi

DEVELOPMENT OF HIGH STRENGTH CONCRETE WITH LOCALLY AVAILABLE MATERIALS

By

Arshad Mahmood

A Thesis

of

Master of Science

Submitted to the

National Institute of Transportation

Risalpur

National University of Sciences and Technology

Rawalpindi

In partial fulfillment of the requirements

For the degree of

Master of Science in Civil Engineering

2006

DEDICATED

TO

MY PARENTS, WIFE, TEACHERS

AND

WELL WISHERS

ACKNOWLEDGEMENT

I am thankful to All Mighty Allah who enabled me to accomplish this research work. I am deeply indebted to the thesis supervisor Brigadier Dr. Tayyeb Akram for encouraging me in the selection of this topic for study and his thought provoking guidance extended. I greatly appreciate his efforts and encouragement displayed throughout the period of study.

I owe special thanks to my respectable teacher Lecturer Skaukat Ali for his consistent and dedicated guidance for this research work. He took personnel interest in streamlining the scope of the research work and extended all out help. I extend warm and best wishes to the MCE Concrete Laboratory Staff, without the technical assistance of whom it would not have been possible to carry out most of the experimental work.

I am also thankful to the administration of the National Institute of Transportation for their help extended in the research work.

Special thanks are due to my parents and wife for their encouragement, sincere prayers and patience.

ABSTRACT

Recent developments in concrete technology, especially during the last decade have made it possible to produce the High Strength Concrete (HSC) on commercial scale. The advantages of using high strength concrete are numerous, as it can economize variety of construction works such as long span bridges, off-shore structures and high rise buildings. The concrete mixtures contain high cement contents, low water cement ratio, high quality aggregates and several admixtures (such as a super plasticizer and Pozzolan). When properly mixed, consolidated and cured, such mixtures give high strength, durability and excellent performance.

For this research 25 mix designs were prepared to study the effect of addition of silica fume ranging from 5 to 25 percentages with varying water to cementitious ratio i.e. from 0.18 to 0.26. The aggregate from Kiriana hills (Sargodha) and sand from Lawrancepur was used in the experimental work.

The strength development results are analyzed and an optimum percentage of 15 per cent silica fume is recommended for the economy of HSC.

.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter-1

INTRODUCTION

1.1 GENERAL

Since the 1850s, concrete as a construction material has undergone a continuous evolutionary process. Compressive strength of 2000 psi was considered adequate at the turn of the twentieth century. Today concrete having compressive strengths of 20000 psi are being used in columns of high rise buildings and in few European bridges (Nawy 1996). The development of concrete technology has been a slow evolutionary process. The high compressive strength concrete mixtures are generally characterized by low water to cement ratio, high cement content, and presence of several admixture types, such as water reducing, set retarding, and mineral admixtures (Mehta and Aitcin 1990). The introduction of new admixtures (i.e. superplasticizers) and cementitious materials has allowed the production of highly workable concrete with superior mechanical properties and durability. The accelerated developments in concrete research over the past 20 years have opened new and more proficient utilization of components available in nature, including industrial waste. The thrust in this accelerated activity has been made or justified because of the economical gains in producing stronger structures that are smaller in component dimensions while larger in space availability (Nawy 1996). This new class of concrete is named as high strength concrete (HSC) and also as high performance concrete (HPC) (Sarkar 1991).

The definition of HSC has changed with advancement in technology. In 1954, the concrete with a compressive strength of 8000 psi was used in a 35-storey building in Cuba was considered high strength (Smith and Rad 1989). In 1972, 9000 psi concrete was produced for the construction of 50-storey Mid-Continental Plaza Building in Chicago (Smith and Rad 1989). The design strength of pacific First Centre (Randal and Foot 1989) was 14000 psi, however, the actual strength achieved was 18000 psi.

A great deal of ground has been covered since HSC was first used. Nowadays, compressive strength excess of 8695 psi for high-rise buildings is very common. Indeed, reports on very high strength concrete excess of 15000 psi are no longer infrequent (Sarkar 1991).

1.2 ADVANTAGES OF HSC

HSC is likely to have a somewhat higher initial cost per unit volume than conventional concrete; however, its use is likely to be justified by saving in overall cost. The advantages of using high strength concrete often balance the increase in material cost. The following are the major advantages that can be accomplished (Nawy 1996).

- The reduction in the member size, resulting in
    - Increase in retainable space.
    - Reduction in the volume of the produced concrete with the accompanying saving in construction time.
- Reduction in the self-weight and superimposed dead load with the accompanying saving in smaller foundations.
- Enhanced mechanical properties.
- Ease of placement and compaction without segregation.
- Ideally suited for high-rise building construction.
- Reduced time lag for form works and reduced construction cost.
- Higher resistance to freezing and thawing, chemical attacks, and significantly improved long term durability and crack propagation.

1.3 PHILOSOPHY OF HIGH STRENGTH CONCRETE MIXTURES

High strength concrete mixtures are generally characterized by low water to cement ratio, high cement content, and presence of admixture types, such as water reducing, set retarding, and mineral admixtures like fly ash, ground blast furnace slag, and Silica fumes (SF). To make the high strength concrete from locally available materials, there are no well defined guide lines similar to the ACI 211 Recommended Practice for Selecting Proportions for concrete mixtures. The material and mix proportions are to be selected empirically by extensive laboratory testing. It is well established fact that production of high strength concrete is largely depending on the following factors (Mehta and Aitcin1990).

- Comparatively larger amount of cement quantity.
- Lesser water to cementitious material ratio.
- Stronger and comparatively smaller sized coarse aggregate.
- Use of suitable High range water reducing concrete admixture.

1.4 SCOPE

The scope of this research to produce HSC with following parameters:

- Use of indigenous materials construction with silica fume.
- Water to cementitious material ratios ranging from 0.18 to 0.26
- Varying percentage of SF i.e. 5, 10, 15, 20, and 25 per cent.
- Use of high range water reducing agents (HRWRA).

1.5 OBJECTIVES

The objectives of the research are as under:

- Selection of suitable aggregates for HSC mix.
- Evolve mix design for HSC, with compressive strength higher than 13,000 psi using indigenous material and by varying water to cement ratio and SF percentage.
- To study the effects on strength development of HSC due to the addition of SF.
- Study the properties of the design evolved as above to include:
    - Compressive strength and tensile strength.
    - Comparison of modulus of elasticity with SF percentage of the mix designs with optimum water cement ratio.

Chapter-2

LITERATURE REVIEW

2.1 GENERAL BACKGROUND

Presently, the economical strength limit of HSC approaches the 21750 psi mark. The interest in the use of HSC has expanded significantly, particularly with the availability of high range water reducing admixtures (HRWRA), effective retarders, and supplementary cementitious materials (Sarkar 1991).

It appears that HSC is primarily for high-rise buildings. However, there has been growing interest in HSC among bridge designers because it can reduce structural deadweight. This, in turn, translates into longer spans and fewer girders, while providing improved durability. The investigation of US Federal Highway Administration, has demonstrated that increasing strength from 5000 psi to 7000 psi increases the AASTHO girder span capability by 15 per cent (Rabbat and Russell 1982). The Ile de Re Bridge constructed in France, 1987 had the box girder specified strength of 5800 psi, whereas, the actual strength achieved was of 8700 psi (Sarkar 1991).

In many respects, HSC can be regarded as high performance concrete (HPC), since it goes beyond higher strength to provide durability that can be of greater importance. In this sense, durability can refer to resistance to corrosion, freezing and thawing, alkali aggregate reactivity, chemical attack, abrasion, chloride ion permeability, or any combination thereof.

The economic benefits that can accrue from the use of HSC need not be overemphasized. These were reviewed by ACI Committee 439 (1973), and concluded that the use of HSC outweighs the additional expense; higher economy can be obtained with HSC than with high strength steel.

In terms of engineering characteristics HSC yields a higher modulus of elasticity, greater stiffness, reduce deflection, and less creep. Enhanced performance translates into reduced reinforcement requirements, while HSC’s high early strength mean forms can be stripped sooner. Both provide savings (Sarkar 1991).

2.2 RELATED STUDIES

Wee et al. (1995) studied the effects of type of mixer and mineral admixture on the workability and compressive strength of high strength concrete. The tilting drum mixer was found to be able to perform like the pan mixer in producing HSC with compressive strength higher than 14500 psi. The relationship between cylindrical specimen and cube specimen of HSC was also studied. Like the pan mixer, the tilting drum mixer can also be used to produce HSC containing various mineral admixtures that usually have a high viscosity. With the same water to binder ratio of 0.3, the (cylinder) compressive strength of concrete containing ordinary Portland cement with SF can be 1450 psi higher than that of concrete containing only ordinary Portland cement or ordinary Portland cement with blast furnace slag for the same curing age.

Wee et al. (1995) carried out research to indicate the effect of type of mineral admixture on the relationship between the compressive strength, the splitting tensile strength and the flexural strength of HSC. The ratio of splitting tensile strength to compressive strength was found to be independent of the type of mineral admixture used, but the ratio of flexural strength to compressive strength varied with the type of mineral admixture in concrete. The ratio of splitting tensile strength with respect to compressive strength is l/17 to l/18 irrespective of type of mineral admixtures used. Concrete containing ettringite based cementitious material has a higher compressive strength even though it has a larger total pore volume per unit gram of paste, because it has less large pores as compared to concrete containing other mineral additives. These results show that the mechanism of producing high strength concrete does not only depend on the total pore volume of hardened cement matrix but also on the pore size distribution and the morphology of the hydration products.

Jianyong and Pei (1996) presented the study on changes of the mechanical properties, including compressive strength, split tensile strength and rupture strength of HSC, caused by the addition of ground blast furnace slag and SF. The study indicates that the mechanical properties of HSC were improved to a great extent at later ages when cement used in concrete was replaced by slag and SF by 25 Per cent by weight. The appropriate dosage of slag and SF is both l0 to15 per cent of the total weight of bonding materials in concrete. The addition of ground slag and SF may relatively accelerate the growth of split tensile strength and rupture strength compared with compressive strength, but the fundamental relationship between the developments of three strengths is unchanged.

Mak and Torii (1999) carried out the research to study the strength development of high strength concrete with and with out SF under the effect of high hydration temperatures. They suggested that combined influence of limited moist curing and high hydration temperatures might significantly influence the progress of hydration. This can affect the long-term development of in situ strength and other engineering properties. The SF concrete subjected to high early temperatures showed significantly lower strengths when compared to concrete cured at standard temperature. High early age temperatures significantly accelerate the 7 day strength of high strength SF concrete with no significant increase in strength thereafter when compared to concrete cured at standard temperatures.

Wu et al. (2000) carried out tests to study the effect of the coarse aggregate type on the compressive strength, splitting tensile strength, fracture energy, characteristic length, and elastic modulus of concrete produced at different strength levels with 28 day target compressive strengths of 4350, 8700, and 13050 psi, respectively. The results show that the strength, stiffness, and fracture energy of concrete for a given water to cement ratio depend on the type of aggregate, especially for high-strength concrete. The team suggested that as the strength of the concrete improves; the brittleness of concrete is also increased, which limits the use of the concrete. Therefore, selecting high strength aggregate with lower brittleness, proper texture and mineralogical characteristics may improve the mechanical properties of HSC.

Donza et al. (2002) presented two aspects of the effect of crushed sands on HSC. First, the performance of crushed sands in relation to natural sand using a low water to cement ratio and fixed coarse aggregate and cement content is analyzed. It presents a higher strength than the corresponding natural sand concrete at all test ages, while its elastic modulus is lower at 28 days and is the same after that. Second, the influence of the mineralogical source of the crushed sands was studied using three different types of crushed sands (granite, limestone and dolomite) with similar grading. Results show the adverse effects of shape and texture on workability of concrete, but the compressive strength of concrete is improved. The author recommends that HSC having similar or better mechanical strength than concrete with natural sand can be produced using crushed sand as fine aggregate. Crushed sands require a higher dosage of admixture to overcome the adverse shape and texture of particles.

Jih and Dongyen (2003) from The School of Civil Engineering, Asian Institute of Technology (SCEAIT) set a new record for the Thailand by producing a concrete of 31900 psi by using SF in the concrete mix proportions. The aim of the research was focused on the production of strength aspect, not necessarily satisfying workability and economic requirements of particular application. During the research work the team tried different trial mixes encompassing max 40 per cent SF in the mix proportions. The water cementitious ratio was kept very low to an extent of 0.12. The workability was improved by adding superplasticizer up to 5 per cent by the weight of cementitious material. The paper very briefly explains the methods of mixing, casting and curing the specimens in the laboratory.

Chapter 3

EXPERIMENTAL INVESTIGATION

3.1 GENERAL

To achieve the objectives set for the research study efforts were made to procure the locally manufactured and readily available materials, except for one ingredient i.e. SF, which was not locally available in abundance and had to be imported from Dubai. A brief perspective on the material used and experimental/testing procedures followed for the research programme are summarized in the succeeding paragraphs.

3.2 ESTABLISHMENT OF VARIABLES AND CONSTANTS

The HSC material constituents used in the course of this research, based on availability of time and literature review were divided in two categories, the variable and constant constituents. Two variables, water to cementitious ratio and percentage of silica fume were selected.

The following constituents were kept constant:

- Use of indigenous construction materials with silica fume.
- Dosages and type of HRWRA.
- Size and grading of coarse aggregate.
- Grading of fine aggregate.

3.3 MATERIALS

3.3.1 Cement

The Type I cement, used for this research is manufactured by Askari Cement. It conforms to ASTM C 150 and C 595. Results of the tests carried out to ascertain the properties of cement are presented in Table 3.1. Variation in the chemical composition and physical properties of the cement affect concrete compressive strength more than variations in any other single material (ACI 211.4R-93).

Table 3.1. Properties of Cement

Properties of cement		
Tests	Test results	Specifications
Specific gravity	3.10	ASTM C 188
Initial setting time	150 minutes at 17 ^{0}C	ASTM C 191
Final setting time	390 minutes at 17 ^{0}C	ASTM C 191

3.3.2 Fine Aggregate

For the research purpose sand from different sources was procured. The fineness modulus (FM) did not come with in the required range of 2.70 and 3.20. To resolve the issue sand from Lawrancepur and Margala pan crush was mixed together to bring the value of fineness modulus to 2.93. Results of the tests conducted for verification of properties of sand are tabulated in Table 3.2. For this research the quantity of sand in all 25 mix designs was kept constant, as the role of sand in strength development in high strength concrete is not that pronounced as compared to other ingredients (National Crushed Stone Association 1975). The gradation of the fine aggregate is tabulated in Table 3.3 (Appendix I) and graphically shown in Fig. 3.1 (Appendix I).

Table 3.2. Properties of Fine Aggregates

Properties of fine aggregates		
Tests	Test results	Specifications
Specific gravity	2.62	ASTM C 128
Absorption	0.01	ASTM C 128
FM	2.93	ASTM C 33

3.3.3 Coarse Aggregate

Samples from Margala, Kiriana, and Kala Chita range being the well know sites for better quality of aggregate were collected. The laboratory test results for the three aggregate sources are tabulated in Table 3.4. Comparison of the test results indicate that crushed aggregate from Kiriana hills has best physical properties such as low impact of 7.2 per cent, and crushing value of 9.5 per cent, and high specific gravity of 2.71.

For this research the quantity of coarse aggregate in all mix designs was kept constant. Maximum size for the aggregate was kept as 0.5 in. For gradation purposes only three sizes were considered i.e. 1/2 in., 3/8 in., 3/16 in. The gradation and sieve analysis was determined in accordance with ASTM C 136 – 93 and tabulated in Table 3.5 (Appendix I) and graphically illustrated in Fig. 3.2 (Appendix I).

Table 3.4. Comparisons of Aggregate Properties

Sample	Impact value (per cent)	Crushing value (per cent)	Abrasion value (per cent)	Specific gravity
Margala	15.2	21.6	19.2	2.7
Kiriana	7.2	9.5	8.9	2.91
Kala Chita	16.2	22.5	19.2	2.81

3.3.4 Silica Fumes

For the purpose of this research SF was selected as a Pozzolanic cementitious material. SF produces best high early strength and durable concrete as compared to other pozzolanic materials (ACI 363R - 92). The SF inclusion in the concrete mix increases the water demand and there by reduces the workability. More recently, the availability of HRWRA has opened up new possibilities for the use of SF as part of the cementing material in concrete to produce very high strength or very high level of durability or both (ACI 234R - 96).

In this research work SF percentage was varied from 5 to 25 per cent with the increment of 5 per cent to see the effect on strength development and to determine the optimum percentage keeping in view the economy of the mix design. The chemical composition of the SF is tabulated in Table 3.6.

Table 3.6. Chemical Compositions of SF

Chemical composition	Percentage
SiO_2	92
Al_2O_3	0.6
Fe_2O_3	1.0
CaO	0.4
MgO	1.5
K_2O	0.8
Na_2O	0.5

3.3.5 High Range Water Reducing Agent (HRWRA)

The HRWRA, used in the research, is modified "polycarboxlate" type, commercially branded, as Sika Viscocrete-1. The dosage was kept constant throughout the research work as 4 per cent by weight of cementitious materials. The technical data of Viscocrete-1 is tabulated in Table 3.7.

Table 3.7 Technical Data of Viscocrete-1

Attribute	Aqueous solution of modified Polycarboxlate
Appearance	Greenish liquid
Density	1.10 Kg / Litre
ph-value	6.8

3.3.6 Mixing Water

Potable water from Nowshera was used for entire experimental work including water for curing.

3.4 DEVELOPMENT OF HSC MIX PROPORTIONS

Proportioning a trial mix of HSC is more complex procedure than the normal strength concrete. There is no standard method of proportioning for HSC as it exists for

NSC. It has been observed that key to the “HSC recipe” has been considered as control over the water to cement ratio. So to design high strength concrete mix proportion, lead can be taken from the work already done in this field by various researchers, suiting to the own environment and local materials. In general practice trial mixes are prepared and then these mixes are put under test and trial procedures till the time results are matching with design parameters (ACI 211.4R-92). Following procedure was adopted to finalize the mix design for this research study.

3.4.1 Concrete Optimization Software Tool (COST)

COST (2001), is a joint product of the Federal Highway Administration and the National Institute of Standards and Technology, USA. The COST is an online interactive system developed to assist engineers, concrete producers, and researchers in optimizing Portland cement concrete mixtures for their particular applications. COST provides an Internet based system for optimizing concrete performance, based on statistical experiment design and analysis methods. Working with local raw materials, COST designs an experimental program of concrete mixtures to be prepared and evaluated. In these mixtures, the user can vary the water to cement ratio and other concrete mixture parameters such as the cement, mineral and chemical admixture, and aggregate contents. Once the measured responses (properties) for the prepared concretes are input into the COST system, it analyzes the results and determines the optimum mixture proportions based on user supplied performance criteria. There are two scenarios for which COST could be applied:

- The first, and probably most common, would be the case where a user wants to proportion a concrete mixture to meet a set of specifications at minimum material cost.
- The second is the case where the user wants to maximize (or minimize) a particular response or responses, irrespective of cost.

HSC mixtures, which may be required to meet several performance criteria (e.g., compressive strength, elastic moduli, and rapid chloride permeability) simultaneously, typically contain at least six components. Thus, optimizing mixture proportions for HSC, which contains many constituents and is often subject to several performance constraints, can be a difficult and time consuming task.

COST can be used to optimize cement paste, mortar, or concrete mixtures. In all three cases, varying the mixture component proportions affects both fresh and hardened properties of the paste, mortar or concrete. The properties (responses) depend on the proportions of the components. Table 3.8 illustrates the list of typical components and responses for concrete mixtures.

Table 3.8 Examples of Components and Responses

Components	Responses
Water Cement (including blended cements) Mineral admixtures (e.g., fly ash, SF, slag,) Chemical admixtures (Water reducers, retarders, air entraining agents) Aggregate	Fresh properties (e.g., slump, air content, unit weight, temperature, set time) Mechanical properties (e.g., strength, modulus of elasticity, shrinkage) Durability (e.g., freeze-thaw, scaling, alkali silica reaction, sulfate attack, abrasion)

3.4.2 Commercially Tested Mix Designs

To seek the guidance for finalizing the mix design for the research work in hand, a critical analysis of the commercially used/tested mix design was also done. Features suiting our requirements and environment were incorporated for mix trials leading to final mix designs/proportions to be analyzed. A few of the commercially tested mix designs (Holland 2005) are given in Tables 3.9 (Appendix I).

3.4.3 Trial Mix Proportions/Designs

After going through the above process 10 trial mix proportions were cast. These trial mix proportions were tested for slump and 7-days compressive strengths. Trial mix number 2 was selected based on compressive strength and workability, for the final experimental programme. The details of trial mixes are given in Table 3.10 (Appendix I).

3.4.4 Workability of Fresh Concrete

In HSC the concept of low water to cementitious ratios retard the characteristics of fresh concrete like workability to its minimum. By use of HRWRA the reduction in workability due to low water to cementitious ratios is improved.

After the selection of final mix, another set of trial mixes was carried out to ascertain the optimum dosage of HRWRA to produce required slump of 50 mm for varying percentages of SF. The dosage rate and slump values are tabulated in Table 3.11. An optimum HRWRA dosage of 4 per cent is selected as constant in the final mix design.

Table 3.11 Workability of Various Mixes

Percentage of silica fume	Slump values (mm)		
	Using 2 per cent of HRWRA	Using 3 per cent of HRWRA	Using 4 per cent of HRWRA
0	50	65	85
5	45	60	80
10	40	50	75
15	35	45	60
20	30	40	50
25	25	30	45

3.4.5 Final Mix Proportions/Designs

Basic mix design was repeated for 30 times for different varying combinations of SF (0, 5, 10, 15, 20 and 25 per cents) and water to cementitious ratios (0.18, 0.20, 0.22, 0.24, and 0.26) to achieve maximum compressive strength and to determine optimum percentage of SF. The mix proportions are tabulated in Table 3.12 (Appendix I).

3.5 WATER TO CEMENTITIOUS MATERIAL RATIO

The single most important variable in achieving high strength concrete is the water to cement ratio. The relationship between water to cementitious ratio and compressive strength, which has been identified in NSC, has been found to be valid for HSC as well. The use of chemical admixtures and other cementitious materials has been proven generally essential for producing place able concrete with low water to cementitious ratio. Water to cementitious ratio for HSC is typically ranged from 0.20 to 0.5 (ACI 211. 4R-93).

In this research experimental work was planned at very low water to cementitious ratios ranging from 0.18 to 0.26. Due to very low water to cementitious ratio workability problems were anticipated, therefore, best quality of commercial superplasticizer "VISCOCRETE-1" available in Pakistan was used.

3.6 MIXING

The mixing of HSC ingredients is little different from NSC mixing. Especially if the mix design is based on SF, since the concrete containing SF require very care full and calculated mixing of ingredient. Over mixing of such concrete may produce adverse effect on strength development of the concrete. While preparing concrete in the laboratory, the key is batching the SF at the appropriate time and then mixing the concrete adequately. ASTM C 192, Standard Practice for Making and Curing concrete Test Specimens in the laboratory recommends: "Mix the concrete, after all the ingredients are in the mixer, for 3 minutes, followed by a 3 minutes rest, followed by a 2 minutes final mixing". These recommended mixing times were found not enough to break down the agglomerations and to disperse the SF.

Therefore, the following procedure was adopted to mix the ingredients to attain the full dispersion of admixtures in the mix (Holland 2005).

- SF must always be added with the coarse aggregate and some of the water. Batching SF alone or first can result in head packing or balling in the mixer. Mix SF, coarse aggregates, and water for 0.5 minutes.
- Add the Portland cement and any other cementitious material if any. Mix for an additional 1.5 minutes.
- Add the fine aggregate and use the remaining water to wash in chemical admixtures added at the end of the batching sequence. Mix for 5 minutes, rest for 3 minutes, and mix for 5 minutes. If there are doubts that full

dispersion and efficient mixing has not been accomplished, mix longer. However, SF concrete cannot be over mixed.

3.7 CASTING OF SPECIMEN

Casting of specimens was carried out as per ASTM C 192M - 02. For tests on compressive strength, tensile strength, and modulus of elasticity, cylinders were prepared, whereas, for flexural strength test, beams were prepared. Three specimens for each test were prepared according to the specifications of ASTM C 192M – 02.

3.8 MIX DESIGNS/SPECIMEN DESIGNATION

The research work was based on final mix design constituting 30 sub mix designs for varying percentages of silica fumes and water to cementitious ratios. For clarity purposes a system of specimen designation was devised based on M-*X*-*Y*- *Z* symbols. The description of these symbols is as follow:

- M – stands for Mix
- *X* - denotes the percentage of the silica fumes in the mix designs i.e. 00, 05, 10, 15, 20, and 25 per cent.
- *Y* - denotes the water to cementitious ratios of the mixes i.e. 0.18, 0.20 0.22, 0.24 and 0.26.
- *Z* - denotes the specimen number

The mix designated as M-05-0.22-6, describes basic mix design having, 05 percent SF, 0.22 water to cementitious ratio, and specimen number 6.

3.9 TESTING PLAN OF SPECIMENS

A comprehensive test plan, developed for determining the compressive strength of the final mixes is tabulated in Table 3.13. Based on the compressive strength tests results, optimum water cementitious ratio was determined. Further testing for tensile strength, flexural strength and modulus of elasticity were planned for mixes with optimum water cementitious ratio only. These tests were carried out at age of 28 days.

The detailed test plan on mixes with optimum water cementitious ratio is tabulated in Table 3.14.

Table 3.13 Test Plan for Determining Compressive Strength of Final Mixes

Mix design	Percentage of silica fumes	w/cm ratios	Compressive strength (number of cylinders)		
			7 days	14days	28 days
M-00-0.18	0	0.18	3	3	3
M-05-0.18	5	0.18	3	3	3
M-10-0.18	10	0.18	3	3	3
M-15-0.18	15	0.18	3	3	3
M-20-0.18	20	0.18	3	3	3
M-25-0.18	25	0.18	3	3	3
M-00-0.20	0	0.20	3	3	3
M-05-0.20	5	0.20	3	3	3
M-10-0.20	10	0.20	3	3	3
M-15-0.20	15	0.20	3	3	3
M-20-0.20	20	0.20	3	3	3
M-25-0.20	25	0.20	3	3	3
M-00-0.22	0	0.22	3	3	3
M-05-0.22	5	0.22	3	3	3
M-10-0.22	10	0.22	3	3	3
M-15-0.22	15	0.22	3	3	3
M-20-0.22	20	0.22	3	3	3
M-25-0.22	25	0.22	3	3	3
M-00-0.24	0	0.24	3	3	3
M-05-0.24	5	0.24	3	3	3
M-10-0.24	10	0.24	3	3	3
M-15-0.24	15	0.24	3	3	3
M-20-0.24	20	0.24	3	3	3
M-25-0.24	25	0.24	3	3	3
M-00-0.26	0	0.26	3	3	3
M-05-0.26	5	0.26	3	3	3
M-10-0.26	10	0.26	3	3	3
M-15-0.26	15	0.26	3	3	3
M-20-0.26	20	0.26	3	3	3
M-25-0.26	25	0.26	3	3	3

Table 3.14 Test Plan for Final Mixes with Optimum Water Cementitious Ratio

Mix design	Number of specimens tested at 28 days		
	Tensile strength	Flexural strength	Modulus of elasticity
M-00-0.22	3	3	3
M-05-0.22	3	3	3
M-10-0.22	3	3	3
M-15-0.22	3	3	3
M-20-0.22	3	3	3
M-25-0.22	3	3	3

Chapter 4

TEST RESULTS AND ANALYSIS

4.1 GENERAL

All tests were performed according to ASTM designated procedures; test results of minimum of three specimens were considered for any result in specific condition/age. Basing on the test results the properties of the fresh and harden concrete like compressive strength, flexural strength, tensile strength and modulus of elasticity were analyzed. The analysis of the results is discussed in succeeding paragraphs.

4.2 COMPRESSIVE STRENGTH TEST RESULTS

Since much of the interest in HSC is limited only in compression, compressive strength measurements are of primary concern in the testing of HSC. Therefore, properties of HSC are predominantly governed by compressive strength.

4.2.1 Results

The 30 mix proportions prepared during the research work were tested for the compressive strength. The maximum compressive strength attained is 15574 psi. The results of all the trial mixes have been tabulated in Tables 4.1 to 4.5 (Appendix II). The trend of compressive strength development in 30 mix proportions at 7 days, 14 days and 28 days showing the effect of water to cementitious ratios and different percentages of silica fume is shown in Fig. 4.1 to 4.5 (Appendix II).

4.2.2 28 Days Compressive Strength Results

The maximum compressive strength of 15574 psi at 28 days was attained with 0.22 water to cementitious ratio and 25 per cent of SF. The relative increase in compressive strength compared to mix with zero percent SF is 32, 40, 51, 54, and 58 per cent for 5, 10, 15, 20, and 25 per cent SF content respectively. The results are tabulated in Table 4.6.

Table 4.6. Compressive Strength Results of Concrete with Varying SF Contents at 0.22 w/cm ratio

Mix	SF percentage	W/cm	7 Days Strength	14 Day Strength	28 Day Strength
M1-00-0.22	0	0.22	5890	7250	9860
M1-05-0.22	5	0.22	8921	11623	13025
M1-10-0.22	10	0.22	9552	12584	13824
M1-15-0.22	15	0.22	10522	13652	14885
M1-20-0.22	20	0.22	10873	13879	15217
M1-25-0.22	25	0.22	10969	14346	15574

4.2.3 Effect of Water to Cementitious Material Ratio

Results of 28 days compressive strength of each mix proportion are shown in Tables 4.1 to 4.5 (Appendix II). Generally, the results of all the mix proportion show a similar trend of compressive strength variation with water to cementitious ratio.

The compressive strength comparison shown in the Fig.4.6 indicates that water to cementitious ratio range from 0.18 to 0.22 increases compressive strength. The compressive strength reduces from 0.22 to 0.26 water to cementitious ratios. Table 4.7 shows the effect of water to cementitious ratio on workability of the mixes. Slump reduces from 65 mm to 30 mm as the water to cementitious ratio is reduced from 0.26 to 0.18. At water to cementitious ratios below 0.22, the workability is so reduced that it hinders proper compaction. Similar findings are reported in paper by Ali et al. (2001). For water to cementitious ratio above 0.22, slump increases but the increase in the water content also decreases the compressive strength. It concludes that 0.22 is the optimum water to cementitious ratio for constant HRWRA dosage (4 per cent), and it is independent of SF percentage.

Table 4.7. Workability of Various Water to Cementitious Ratios

w/cm	0.18	0.20	0.22	0.24	0.26
Slump	30 mm	35 mm	45 mm	55 mm	65 mm

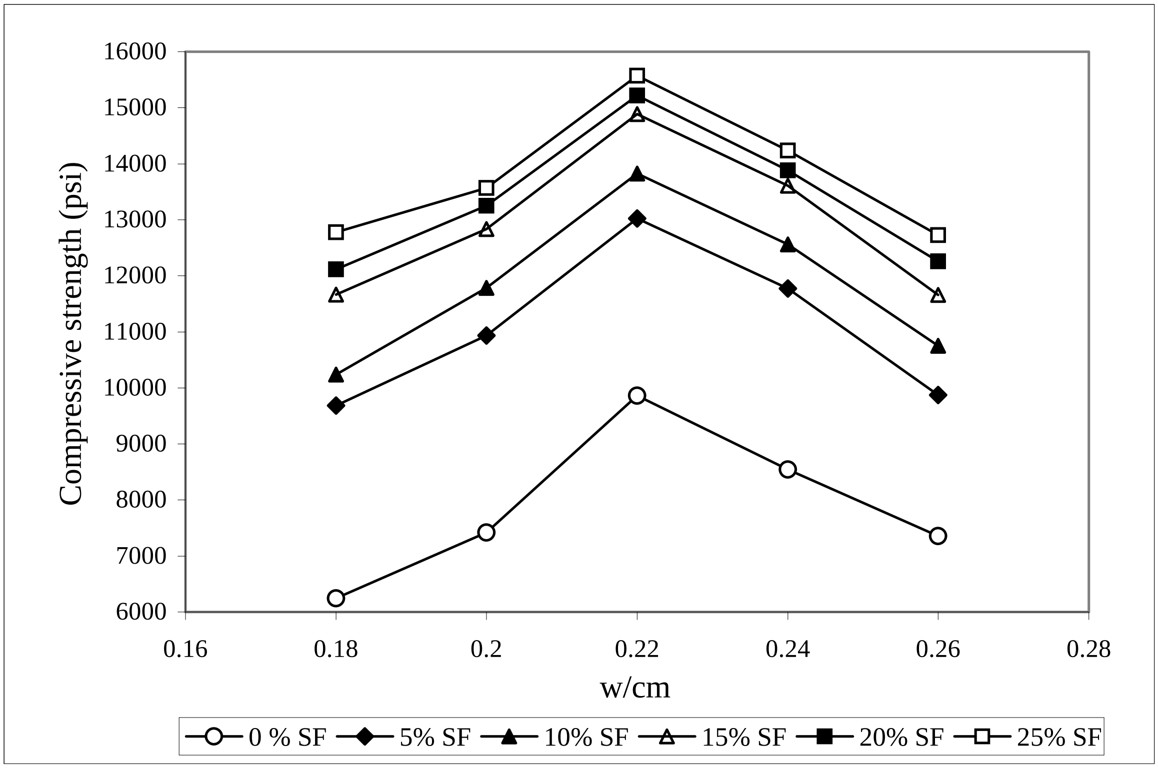

Fig. 4.6. Effect of w/cm ratios on concrete compressive strength with varying SF % age

4.2.4 Effect of Silica Fumes

The analysis of compressive strength results given in Tables 4.1 to 4.5 (Appendix II), indicate that there is always an increase in the compressive strength with the increasing percentage of SF. However, the rate of increase in the compressive strength differs with the varying percentages of the SF. The phenomenon of compressive strength increase with varying percentage of SF is graphically illustrated in Fig. 4.7. It is also clear from the Fig.4.6, shown above, that water cementitious ratio of 0.22 gives maximum compressive strength for all SF percentages.

The trend in the Fig. 4.7 indicates that there is a sharp increase of 51 per cent in the compressive strength at 15 per cent of SF content. However, further increase in SF contents to 25 per cent results in additional improvement in compressive strength by 7 per cent. Therefore, it can be concluded that the optimum SF percentage is 15 per cent. Similar conclusion is drawn by Khedr and Zeid (1994), where they reported an optimum SF content of 15 to 20 per cent.

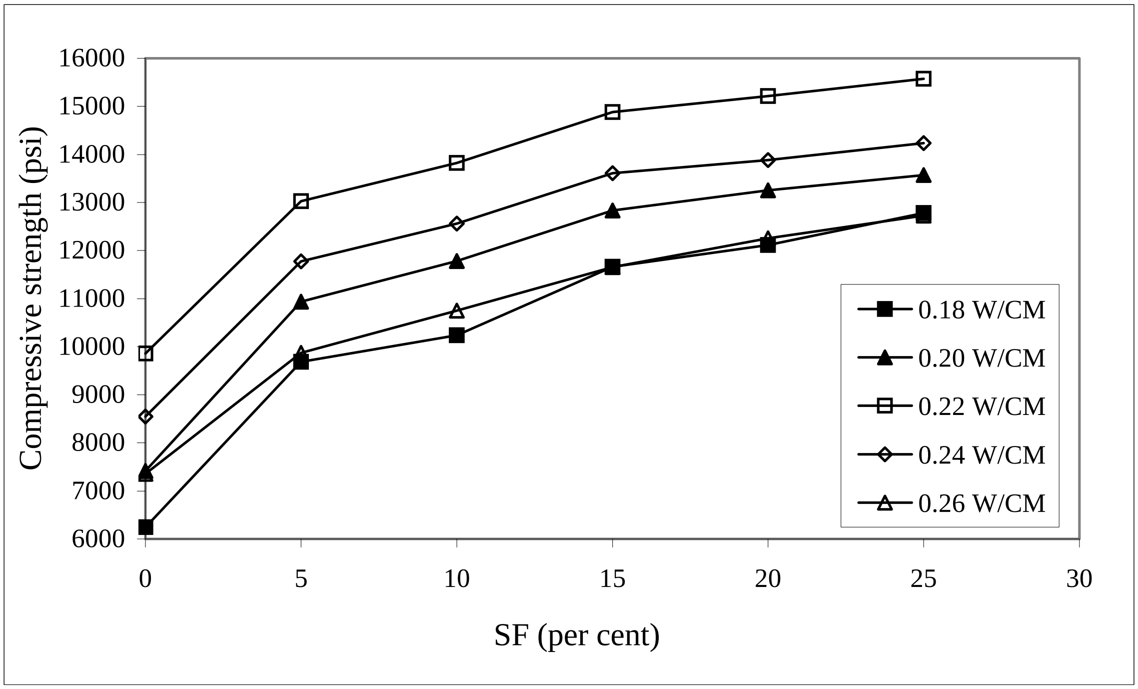

Fig. 4.7. Effect of SF percentage on concrete compressive strength comparison with varying w/cm

4.2.5 Effect of Age

The analysis of Figs. 4.1 to 4.5 (Appendix II) indicates that the rate of increase of compressive strength is very high in initial 7 days and to some extent up to 14 days but very minimal after 14 days.

The rate of increase in compressive strength between 7 to 14 days is 21 per cent and between 14 to 28 days is 11 per cent for mix with 15 per cent SF. The results are shown in Fig.4.8. The trends indicate that rate of compressive strength gain is reduced with time, and the compressive strength gain is a non linear function of time. Similar trends were observed by Khedr and Zeid (1994).

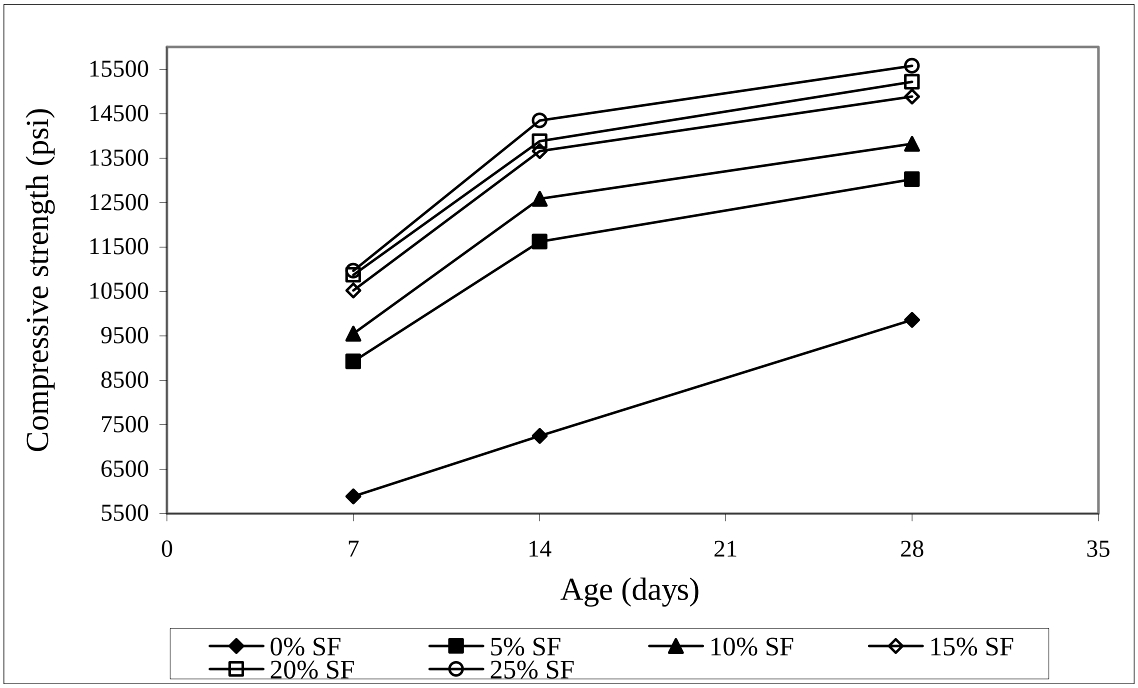

Fig. 4.8. Effect of time on concrete compressive strength with varying percentages of SF at 0.22 w/cm

4.3 TENSILE STRENGTH

The 28 days tensile strength of concrete is tested for optimum water to cementious ratio of 0.22, results are summarized in Table 4.9 and graphically represented in Fig. 4.9 (Appendix II). Comparisons of results show, that for increase in SF percentage from 5 to 25 per cent, the tensile strength gain is 23 per cent, whereas, the compressive strength gain is about 20 per cent.

Table 4.8. 28 Days Tensile Strength Results for Mixes with 0.22 w/cm

SF percentage	Water to cementitious ratio	Tensile strength (psi)
		28- Days strength
0	0.22	530
5	0.22	790
10	0.22	905
15	0.22	940
20	0.22	955
25	0.22	975

4.4 FLEXURAL STRENGTH

The 28 days flexural strength of concrete is tested for optimum water to cementious ratio of 0.22, results are summarized in Table 4.10 and graphically represented in Fig. 4.10 (Appendix II). Comparison of results shows, that for increase in SF percentage from 5 to 25 per cent, the flexural strength gain is 30 per cent, whereas, the compressive strength gain is about 20 per cent.

Table 4.9. 28 Days Flexural Strength Results for Mixes with 0.22 w/cm

Mix	SF percentage	Water to cement ratio	Flexural strength (psi)
			28- Days
M-00-0.22	0	0.22	775
M-05-0.22	5	0.22	1165
M-10-0.22	10	0.22	1360
M-15-0.22	15	0.22	1455
M-20-0.22	20	0.22	1490
M-25-0.22	25	0.22	1515

4.5 MODULUS OF ELASTICITY

The results of the modulus of elasticity are summarized in Table 4.11 and graphically represented in figures 4.11 (Appendix II). The value of modulus of elasticity determined in this research is 5.2×10^6 psi. Ali et al. (2001) using Basalt aggregate achieved modulus of elasticity value of 6.03×10^6 psi. The difference in moduli values is probably due to different aggregate types used i.e., basalt and limestone.

Table 4.10. 28 Days Modulus of Elasticity Results for Mixes with 0.22 w/cm

Mix	SF percentage	Water to cement ratio	Modulus of elasticity x 10^6 (psi)
			28- Days
M-00-0.22	0	0.22	4.81
M-05-0.22	5	0.22	4.95
M-10-0.22	10	0.22	5.20
M-15-0.22	15	0.22	5.39
M-20-0.22	20	0.22	5.55
M-25-0.22	25	0.22	5.70

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Key conclusions drawn from this research are summarized as follow:

- There is no well defined method for determining mix proportions for HSC, extensive trial mix proportion has to be tried to reach to a desirable mix proportion that will meet the performance requirements.
- Optimum percentage of SF contents is found to be 15 per cent for the economical HSC production.
- Optimum water to cementitious ratio is determined to be 0.22 for HSC.
- Tensile strength and modulus of elasticity increase with the increase in compressive strength; however, the gain in these parameters is not proportional to compressive strength.

5.2 RECOMMENDATIONS

- Durability is the fundamental property of HSC; therefore, a detailed study may be under taken to evaluate the durability of HSC.
- Strength of HSC concrete is affected by the material inputs kept constant during the course of this study (HRWRA type and dosage, cement type and quantity, and aggregate grading). Future study can focus on altering these factors.

REFERENCE

Ali, F. A., Tair, A. A., O' Connor, D., Benmarce, A., and Nadjai, A. (2001). "Useful and practical hints on the process of producing high strength concrete." *Prac. Period. Struct. Des. Constr. 4(4),* 150-153.

American Concrete Institute (ACI). (1977). **"**State of the art report on high strength concrete." *ACI 363R-92,* Detroit.

American Concrete Institute (ACI). (1998). "Guide for selecting proportions for high strength concrete with portland cement and fly ash." *ACI 211.4R-93*, Detroit.

American Concrete Institute (ACI). (2000). "Guide for the use of silica fume in concrete." *ACI 234R-96*, Detroit.

Bickley, J. A., Ryell, J., Rogers, C., and Hoonton, R. D. (1991). *"Some characteristics of high strength structural concrete."* Canadian J. Civ. Eng. 18(5), 889.

"Cost Optimization Software Tool (COST)." (2001). (http://ciks.cbt.nist.gov/cost/) (July, 2001).

Donza, H., Cabrera, O., and Irassar, E.F. (2002). "*High strength concrete with different fine aggregates*." Cement and Concrete Research 32 (2002), 1755-1761.

Forrest, M. P., Morgan, D. R., Obermeyer, J. R., Parker, P. L., and LaMoreaux, D. D. (1995). *"Seisminc retrofit of Littlerock dam."* Concrete International 17(11), 30-36.

Holland, T. C., krysa, A., Luther, M., and Liu, T. (1986). "Use of silica fume concrete to repair abrasion-erosion damage in Kinzua dam stilling basin." *Proc. CANMET/ACI Int. Conf. on the use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete,* Madrid, SP-91(2), ACI, Detroit, 841-864.

Holland, T. C. (2005). "Silica fume user's manual." *Rep. No. FHWA-IF-05-016*, Federal Highway Administration, Washington, D.C., USA.

Jianyong, L., Pei, T. (1997). *"Effect of slag and silica fume on mechanical properties of high strength concrete."* Cement and Concrete Research 27(6), 833-837.

Jih, T. Q. and Dongyen, A. (2003). "Super High Strength Concrete." *Research Rep.,* School of Civil Engineering, Asian Institute of Technology, Thailand.

Khedr, S. A., and Zeid, M. N. A. (1994). “Characteristics of silica fume concrete.” *J. Mater. Civ. Eng., 6(3),* 357-375.

Kosmatka, S. H., kerkhoff, B., and Panarese, W. C. (2005). “Design and control of concrete mixtures.” *Portland Cement Association, Illinois,* 305-307.

Leonard, M. A. (1999). “I-25 over Yale Avenue—The Thin Solution.” HPC Bridge Views, No. 3, June (1999), 2.

Mak, S. L., and Torii, K. (1999). *“Strength development of high strength concretes with and without silica fume under the influence of high hydration temperatures.”* Cement and Concrete Research 25(8), 1791-1802.

Mehta, P.K., and Aitcin, P.C. (1990). “ Microstructural basis of selection of material and mix proportions for high strength concrete.” *Proc., Int. Symp. on High strength concrete*, California, 265-279

National Crushed Stone Association. (1975). *High strength concrete,* Washington, D.C.

Nawy, E. G. (1996). *Fundamentals of High Strength High Performance Concrete.* Longman Group Ltd., Harlow, 81, 268-271.

Rabbat, B. G., and Russell, H. G. (1982). “Optimized sections for precast, prestressed bridge griders.” *Research and Development Bul., No. RD-080-OIE, Portland Cement Assocaition, Illinois.*

Randall, V., and Foot, K. (1989). *“High strength for Pacific First Center.”* Concrete International, 14-16.

Sarkar, S. L. (1991). “High strength concrete and its microstructure.” *Cement and Concrete Science and Technology, Vol. 1, Part 1, Ghosh,* S. N., ed., ABI Books Pvt. Ltd., Delhi.

Smith, G. J., and Rad, F. N. (1989). *“ Economic advantages of high strength concretes in columns.”* Concrete International, 37-43.

Wee, T. H., Matsunaga, Y., Watanabe. Y., and Sakai, E. (1995). *“Production and properties of high strength concrete containing various mineral admixtures.”* Cement and Concrete Research 25(4), 709-714.

Wee, T. H., Matsunaga, Y., Watanabe. Y., and Sakai, E. (1995). *“Microstructure and strength properties of high strength concrete containing various mineral admixtures.”* Cement and Concrete Research 25(4), 715-720.

Wu, K. R., Chen, B., Yao, W., and Zhang, D. (2001). *"Effect of course aggregate size on mechanical properties of high-performance concrete."* Cement and Concrete Research 31(2001), 1421-1425.