FINAL YEAR PROJECT

COMPARATIVE STUDY OF SILICA FUME, FLY ASH AND CEMENT MIXES FOR PRODUCTION OF HIGH STRENGTH CONCRETE

SUBMITTED BY SYNDICATE COMPRISING OF NUST CADETS:

NC- DAULAT ALI
NC- MUSSAIB ALI
NC- ABDUL MUJEEB
NC- RIZWAN WASIM

PROJECT DS: MAJ. (R) SHEHZAD UL HASSAN

MILITARY COLLEGE OF ENGINEERING, RISALPUR
NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY, ISLAMABAD
PAKISTAN

COMPARATIVE STUDY OF SILICA FUME, FLY ASH AND CEMENT MIXES FOR PRODUCTION OF HIGH STRENGTH CONCRETE

By

2009-NUST-BE-Civ-080, NC-Daulat Ali (Syn Ldr)
2009-NUST-BE-Civ-081, NC-Mussaib Ali
2009-NUST-BE-Civ-092, NC-Abdul Mujeeb
2009-NUST-BE-Civ-101, NC-M.Rizwan Wasim

A Thesis

Of

Bachelors of Engineering

Submitted to the

Military College Of Engineering

Risalpur

National University of Sciences and Technology

ISLAMABAD

In partial fulfillment of the requirements

For the degree of

Bachelors of Science in Civil Engineering
2013

Certified that the contents and form of thesis

Entitled

"Comparative study of Silica Fume, Fly Ash and Cement Mixes for production of High Strength Concrete"

Syndicate #17, CED 73

Has been found

Satisfactory for the requirement of the degree.

____

Major (R) SHAHZAD UL HASSAN AMIR

Directing Staff

DEDICATED

TO
OUR

FAMILIES,
TEACHERS,
COLLEAGUES,
WELL WISHERS
AND

MILITARY COLLEGE OF ENGINEERING

ACKNOWLEDGEMENT

We are very much deeply thankful to ALMIGHTY ALLAH Who bestowed us with strength, courage, health and wisdom to execute the project in a benefiting manner. We bow our heads praising Allah Almighty for all the blessings He showered upon us by providing an opportunity to seek and learn.

Completion of this thesis is the result of co-operation of many dedicated and helpful people. It is difficult to gauge their contributions in helping us to carry out this research work.

We are grateful to our College for casting a shroud of temperament, confidence and apprehension on us.

We express our gratitude to our worthy instructor and syndicate DS Major SHAHZAD for the guidance and help he rendered to us. We also acknowledge to all those who during the course of preparation, working and accomplishment of this project helped us in the best possible manner.

We also wish to place on record our humble thanks to the laboratory and technical staff, without the skilled assistance of whom it would not have been possible for us to carry out most of the experiments.

At the end, our gratitude and abundant thanks are due to our parents for showing patience, continued encouragement and their worthy prayers.

ABSTRACT

This paper presents the result of mix design developed for high strength concrete. It involves the process of determining experimentally the most suitable concrete mixes in order to achieve maximum strength with least economic expenditures.

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 Pozzolana). When properly mixed, consolidated and cured, such mixtures give high strength, durability and excellent performance.

. Ordinarily, concrete of substantially higher compressive strength is used for pre-stressed structures than for those constructed of ordinary reinforced concrete. Almost all pre-stressed construction in the world at present is designed for a compressive strength well above 5000 psi.

In this research work, coarse aggregate of nominal specified size from Margala and locally available fine aggregate with specific fineness modulus were used. In this research work four mixes were selected to achieve a compressive strength up to 9000 psi. Four type of mixes for developing HSC were used including pure cement, 12% silica fume, 6% silica fume & 6% fly ash and 12% fly ash as a partial replacement of cement with a fixed water cement ratio of 0.36.Chemrite NN was used as super plasticizer.

TABLE OF CONTENTS

CHAPTER 1 – INTRODUCTION

1.1 DEFINATION OF HIGH STRENGTH CONCRETE - 1

1.2 GENERAL - 1

1.2.1 DIFFERENCE BETWEEN HSC AND CONVENTIONAL CONCRETE - - - -3

1.2.2 THE NEED OF HIGH STRENGTH CONCRETE - - - - - - - - - - - - - - - - - - - 3

1.2.3 ADVANTAGES OF HIGH STRENGTH CONCRETE - - - - - - - - - - - - - - - - 4

1.2.4 LIMITATION OF HSC -5

1.2.5 PHILOSPHY OF HIGH STRENGTH CONCRETE STRUCTURES - - - - - - - 6

1.2.6 WORK ON HIGH STRENGTH CONCRETE IN PAKISTAN - - - - - - - - - - - 7

1.2.7 RESEARCH APPROACH / METHODOLOGY -8

1.2.8 SCOPE AND OBJECTIVES - 8

CHAPTER 2 – LITERATURE REVIE

2.1 SELECTION OF MATERIAL - 9

2.2 NECESSITY OF HSC - 9

2.2.1 HIGH RISE BUILDINGS - 10

2.2.2 BRIDGES - 12

2.2.3 OFFSHORE STRUCTURES - 14

2.3 MATERIAL FOR HSC - 15

2.3.1 ADMIXTURES - 15

2.3.1.1 FACTORS EFFECTING EFFECTIVENESS - - - - - - - - - - - - - - - 19

2.3.2 PORTLAND CEMENT - 20

2.3.2.1 FINENESS - 20

2.3.2.2 CHEMICAL COMPOSITION OF CEMENT - - - - - - - - - - - - - - - 21

2.3.2.3 COMPRESSIVE STRENGTH - 22

2.3.2.4 SETTING TIME AND CONSISTENCY - - - - - - - - - - - - - - - - - - 22

2.3.3 AGGREGATES FOR HSC - 23

2.3.3.1 THE SEARCH FOR STRONG AGGREGATE - - - - - - - - - - - - - - 24

2.3.3.2 COARSE AGGREGATE - 24
2.3.3.3 FINE AGGREGATE - 26
2.3.3.4 MIXING WATER - 27
2.3.4 SILICA FUME - 28
2.3.4.1 THE INFLUENCE OF SILICA FUME ON PROPERTIES OF FRESH CONCRETE - 29
2.3.4.2 THE INFLUENCE OF SILICA FUME ON PROPERTIES OF HARDEND CONCRETE - 30
2.3.5 FLY ASH - 34
2.3.5.1 HIGH RANGE WATER REDUCERS - 36

CHAPTER 3 – SURVEY AN SELECTION OF MATERIALS

3.1 CEMENT - 38
3.2 FINE AGGREGATE - 38
3.2.1 SIEVE ANALYSIS - 39
3.2.2 SPECIFIC GRAVITY AND ABSORPTION - 40
3.2.3 NATURAL MOISTURE CONTENT AND UNIT WEIGHT - - - - - - - - - - - - 41
3.3 COARSE AGGREGATE - 41
3.3.1 GRADING - 43
3.3.2 SPECIFIC GRAVITY AND ABSORPTION -45
3.3.3 CRUSHING VALUES -46
3.4 WATER - 47
3.5 ASMIXTURE USED - 47
3.6 FLY ASH - 47
SILICA FUME -48

CHAPTER 4–HIGH STRENGTH CONCRETE MIX DESIGN AND CASTING

4.1 INTRODUCTION - 49
4.2 SCOPE - 49
4.3 MIXTURE PROPORTIONING - 50
4.3.1 DESIGN STEPS - 51

4.3.1.1 MIX PROPORTION AND BATCH QUANTITIES - - - - - - - - - - - - 55
4.3.1.2 TRIAL MIX PROPORTION - 68
4.4 CASTING OF SPECIMEN - 73
4.4.1 PREPARATION OF MOULDS AND COMPACTION - - - - - - - - - - - - - - - - 73
4.4.2 CAPPING OF MOULDS - 73
4.4.3 DETAILS OF SPECIMES - 73
4.4.4 DEMOULDING AND CURING OF SPECIMEN - - - - - - - - - - - - - - - - - -74
4.5 TESTING MACHINE - 75

CHAPTER 5 – TESTING OF SPECIMEN AND RESULTS

5.1 COMPRESSION TESTING - 76
5.1.1 TEST RESULTS OF CONCRETE - 76
5.2 EFFECT OF AGE ON COMPRESSIVE STRENGTH OF CONCRETE - - - - - - - - - - - 91
5.3 EFFECT OF AGE ON FLEXURAL STRENGTH OF CONCRETE - - - - - - - - - - - - - 92

CHAPTER 6 – CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSION - 93
6.2 COMMENTS - 94
6.3 RECOMMENDATIONS - 95

REFERENCES - 96

LIST OF TABLES

Table 2.1 DIFFERENT TYPES OF WATER REDUCER --19

Table 2.2 CHEMICAL COMPOSITION OF CEMENT ---21

Table 2.3 CHEMICAL COMPOSITION OF SILICA FUME -------------------------------------31

Table 2.4 PHYSICAL PROPERTIES OF SILICA FUME ---32

Table 2.5 COMPARISON OF CHEMICAL & PHYSICAL CHARACTERISTICS OF SILICA FUME, FLY ASH AND CEMENT --32

Table 3.1 INITIAL AND FINAL SETTING TIME ---38

Table 3.2 SIEVE ANALYSIS OF FINE AGGREGATE ---39

Table 3.3 SPECIFIC GRAVITY AND WATER ABSORPTION OF FINE AGGREGATE ----40

Table 3.4 NATURAL MOISTURE CONTENT AND UNIT WEIGHT OF FINE AGGREGATE ---41

Table 3.5 TEST DATA ON COARSE AGGREGATE OBTAINED FROM PREVIOUS THESIS ---42

Table 3.6 GRADING OF COARSE AGGREGATE --44

Table 3.7 PROPERTIES OF COARSE AGGREGATE ---46

Table 4.1 RECOMMENDED SLUMP FOR CONCRETE WITH & WITHOUT HRWR ------50

Table 4.2 SELECTION OF MAXMUM SIZE OF AGGREGATE --------------------------------52

Table 4.3 VOLUME OF COARSE AGGREGATE W.R.T MAX SIZE OF AGGREGATE ---52

Table 4.4 ESTIMATION OF MIXING WATER AND AIR CONTENT -------------------------52

Table 4.5 SELECTION OF W/C RATIO --53

Table 4.6 FIRST ESTIMATION OF WEIGHT OF FRESH CONCRETE -----------------------54

Table 4.7 BATCH QUANTITIES (PURE CEMENT SAMPLES) --------------------------------58

Table 4.8 BATCH QUANTITIES (12 % SILICA FUME SAMPLES) -------------------------- 61

Table4.9B ATCH QUANTITIES (12 % FLY ASH SAMPLES) --------------------------------- 64

Table 4.10 BATCH QUANTITIES (6 % FLY ASH & 6 % SILICA FUME SAMPLES) ---- 67

Table 4.11 DESIGN STEPS (PURE CEMENT) --- 69

Table 4.12 DESIGN STEPS (SILICA FUME 12 %) --70

Table 4.13 DESIGN STEPS (FLY ASH 6 %) ---71

Table 4.14 DESIGN STEPS (FLY ASH 6 % & SILICA FUME 6 %) --------------------- 72
Table 4.15 DETAILS ABOUT SPECIMEN -- 74
Table 5.1 07 DAYS STRENGTH OF CUBES --- 77
Table 5.2 14 DAYS STRENGTH OF CUBES --- 78
Table 5.3 21 DAYS STRENGTH OF CUBES --- 79
Table 5.4 28 DAYS STRENGTH OF CUBES --- 80
Table 5.5 07 DAYSSTRENGTH OF CYLINDERS -- 82
Table 5.6 14 DAYSSTRENGTH OF CYLINDERS -- 83
Table 5.7 21 DAYSSTRENGTH OF CYLINDERS -- 84
Table 5.8 28DAYSSTRENGTH OF CYLINDERS -- 85
Table 5.9 07 DAYS STRENGTH OF PRISMS -- 87
Table 5.10 14 DAYS STRENGTH OF PRISMS -- 88
Table 5.11 21 DAYS STRENGTH OF PRISMS -- 89
Table 5.12 28 DAYS STRENGTH OFPRISMS --- 90

CHAPTER-1

INTRODUCTION

1.1.DEFINATION OF HSC

High-strength concrete has a compressive strength greater than 40 MPa (6000 psi) with very low water to cement ratios.

1.2.GENERAL

Concrete has become primary construction material. The quality of concrete is characterized by its compressive strength since most of its engineering properties i.e., durability, permeability, elastic modulus etc. depend on its compressive strength. In recent years there has been a rapid growth of interest in HSC and the use of HSC is expected to increase in future in our country as it has been in the developed countries.

In the early 1970s, experts predicted that the practical limit of ready mixed concrete would be unlikely to exceed a compressive strength of 11,000 psi . Over the past two decades, the development of high-strength concrete has enabled builders to easily meet and surpass this estimate. Compressive strength as high as 19,000 psi (131 MPa) had been used in two buildings at Seattle, Washington.

The development of concrete technology has been a slow evolutionary process. The concept of achieving relatively higher strength concrete by varying water-cement ratio and air content was discovered in 1919 and 1938 respectively.

The rapid developments in concrete research over the past 30 years have opened new and proficient utilization of components available in nature including industrial “wastes” such as silica fume. The Silica Fume was an industrial “waste” few decades ago but now is an integral element of high strength concrete. The

advancement in this accelerated activity has been made because of the utility, viability, and long-term engineering economy gains in producing stronger structures, which are smaller in dimensions with larger space availability.

The introduction of new admixtures (i.e. super plasticizers) and cementitious materials has allowed the production of highly workable concrete with superior mechanical properties and durability. This new class of concrete has been named as High Strength Concrete (HSC).The definition of HSC has changed with advancement in technology. In *1950,* the concrete with a compressive strength of 5000 psi was considered as high strength concrete. In 1965, 7250 psi concrete was industrially produced for the first time in United States for making columns of the Lake Point tower building in the Chicago. During the 1982, some high rise buildings in New York and Texas contained structural members made with 4000 to 17400 psi concrete. The Nova Scotia Plaza building in Toronto and the Two Union

Square building in Seattle used 13775 and 17400 psi concrete elements, respectively.

It may be noted that the HSC mentioned above was made with industrially available material, using conventional concrete practices. Concrete having compressive strength of 58600 psi has been reportedly produced in the laboratory using special reactive powders.

1.2.1 DIFFERENCE BETWEEN HIGH STRENGTH CONCRETE AND CONVENTIONAL CONCRETE

The primary difference between high-strength concrete and normal-strength concrete relates to the compressive strength that refers to the maximum resistance of a concrete sample to applied pressure. Although there is no precise point of separation between high-strength concrete and normal-strength concrete, the American Concrete Institute defines high-strength concrete as concrete with a compressive strength greater than 6000 psi (41 MPa).

1.2.2 THE NEED FOR HIGH STRENGTH CONCRETE (HSC)

Normal strength concrete is heavy and lacks the required performance characteristics in some large structures. By increasing concrete strengths and performance, the required thickness of concrete members and the cost of concrete structures can both be reduce.

Due to long life, excellent durability and stiffness, HSC is widely being used for columns of tall-reinforced high rise concrete building, long span bridges and offshore structures. In addition to being economically attractive, smaller size of the structure is another attraction offered by HSC. For instance, doubling, the strength of concrete from 5000 psi to 10000-psi leads only to some increase in material cost, however it may lead to a substantial decrease in overall structural cost. 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. Some other advantages of HSC are:

a. The enhanced durability and service life
b. Ease of placement and compaction without segregation
c. The enhanced workability
d. Reduced impact of high early stresses due to pre-stressing and earlier application of service loading and the effects it may have on members at early ages.
e. The enhanced mechanical properties and reduced size of structural elements
f. Longer spans and wider members spacing.
g. High toughness.
h. Volume stability and better control of deformations
i. Increased building height
j. Reduced construction cost.
k. Longer spans and wider members spacing.
l. The early stripping of formwork.

1.2.3 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.

1.2.4 LIMITATIONS OF HIGH STRENGTH CONCRETE

a. High strength concrete is expensive as compared to conventional concrete.

b. Cost of materials used in HSC is much more, especially the price of admixtures used as basic ingredient.

c. Specialized personnel are required in preparation of batch, mixing, placing and compaction.

d. Specialized techniques are required to attain the best possible advantage of properties of high strength concrete.

FAILURE DIFFERENCES BETWEEN HSC &CONVENTIONAL CONCRETE

There are significant differences between the failure mechanism of HSC and conventional concrete. For example HSC fails in an abrupt and brittle manner and has smoother fracture surfaces where as normal strength concrete fails in slightly ductile manner and failure is by bond and not by fracture of aggregate. As a result design standards such as ACI 318-02 restrict the maximum concrete strength that can be used in certain design equations.

RESTRICTIONS ON HIGHER COMPRESSIVE STRENGTH

The restrictions in ACI 318-02 impede the use of concrete with strength greater than 10,000 psi. Because of high brittleness, there is a concern that traditional amount of minimum shear reinforcement must prevent sudden shear failure on the formation of first diagonal tension cracking and in addition must equally control the diagonal tension cracks at service load levels.

1.2.5 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 granulated blast furnace slag, and Silica fumes (SF). To make the high strength concrete from locally available materials, there are no well define 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.

1.2.6 WORK ON HSC IN PAKISTAN

A limited work on HSC has been done in Pakistan. This work is mainly restricted to power stations and few long span bridges. The range of compressive strength used in these works varies from 6000 to 8000 psi. Faisal Mosque at Islamabad, chimneys at thermal power station Muzzafargarh, Centaurus mall and long span bridges at Motorway are few of the projects in Pakistan where HSC has been used.

Besides these, no other significant work on use of HSC has been carried out in Pakistan. However, very limited studies on HSC are in hand at various educational institutions such as University of Engineering and Technology (U.E.T) Lahore, Taxila and Peshawar. In Military College of Engineering (MCE) CED-59 as well as CED-67 carried out research on development of high strength concrete.

Due to obvious advantages, and modern trends in the field of construction, it is imperative that engineer community in Pakistan should share its responsibility and start looking into the mechanics of HSC produced using local material and technology.

1.2.7 RESEARCH APPROACH/METHODOLOGY

The objective of this project was to achieve HSC in the range of 8000psi to 10,000psi.

1.2.8 SCOPE AND OBJECTIVES

The scope of this research work is as under:-

a. Selection of suitable aggregates for HSC mix.

b. To evolve a mix design for high strength concrete in the compressive strength range from 8,000 to 10,000 psi using different mix proportions with same water-cement ratio in addition to a super plasticizers.

c. Study the properties of the design evolved to include:

  (1) Compressive strengths.

  (2) Variation in modulus of rupture with compressive strength.

  (3) Rate of strength development with age.

  (4) To find the optimum percentages of silica fume and fly ash to be used for achieving high strength

CHAPTER-2

LITERATURE REVIEW

2.1 SELECTION OF MATERIAL

Selection of materials for High Strength Concrete production needs special care and precision than Normal Concrete so as to ensure the intended function including strength, durability and workability. An important step in the direction of materials was taken when Subcommittee C-9 on concrete and concrete aggregate developed ASTM Specification C387. Optimum mix design is developed keeping in mind the economic advantage of using locally available materials. For the development of High Strength Concrete,an optimum ratio is established for each variable(ACI 211.4R-93).

2.2 NECESSITY FOR HIGH STRENGTH CONCRETE

High strength concrete (HSC) is a relatively new construction material. With the modern technologies and methods production of concrete even greater than 12000 psi has now become possible in laboratories.

When compared to the conventional normal strength concrete (NSC), High Strength Concrete (HSC) offers significantly better structural engineering properties, such as higher compressive and tensile strengths, higher stiffness, and better durability. Keeping in view the threats of terrorist attacks around the world, structural engineers are now seeking new methods of assessment and prevention of high risk facilities. For many years, high-strength concrete has been used in the columns of high-rise buildings. However, recently there has been increased use of high strength concrete in bridges where both strength and durability are important considerations. The primary reasons for selecting high strength concrete is to produce a more economical product, provide a feasible technical solution, or a combination of both.

At the present time, a cubic yard of high strength concrete costs more than a cubic yard of conventional concrete. High strength concrete requires additional quantities of materials such as cement, silica fume, fly ash, high range water reducers and retarders to ensure that the concrete meets the specified performance and intended functions. However, concrete is only one component in construction, and the total cost of the finished product is more important than the cost of an individual material.Necessity to use high strength concrete in high-rise buildings, bridges and offshore structure is explained in the succeeding paragraphs.

2.2.1 HIGH RISE BUILDINGS

High strength concrete has been used in high rise buildings due to its economic advantages. In simple terms, high-strength concrete provides the most economical way to carry a vertical load to the building foundation. The three major components contributing to the cost of column are concrete, steel reinforcement and form-work. By utilizing high-strength concrete, the column size is reduced. Consequently, less concrete and lesser form-work are needed. At the same time, the amount of vertical reinforcement can be reduced to the minimum amount allowed by the code. The net result is that the least expensive column is achieved. With the smallest size column, the least amount of reinforcement and the highest readily available concrete strength.

According to study by Moreno, the use of 6000 psi compressive strength concrete in the lower columns of 23-story commercial building requires a 34 in square column at cost of $\$0.92/ft^2$. The use of 12000 psi concrete allows a reduction in column size to 24 in square column at cost of $\$0.52/ft^2$ reduction in initial cost, a smaller column size results in less intrusion in the lower stories of commercial space and, thereby, more rentable space. Yet the use of high-strength concrete in the columns has not been limited to tall buildings: parking garages have also used the material to reduce the column sizes. Since column intrude into the layout for parking spaces, a small column is advantageous.

In addition to specifying concrete compressive strength, modulus of elasticity also has been specified for the concrete in several high rise buildings. A higher modulus of elasticity provides a stiffer structure which has less lateral deflection under wind loads.

2.2.2 <u>BRIDGES</u>

In 1993, the Federal Highway Administration (FHWA) initiated a national program to implement the greater use of HSC in bridges. Applications include bridge decks, girders, piers and abutments. Nine bridges had been completed under the national program by the end of 1998. In addition, a number of other states are using HSC under their own programs. The use of high strength concrete in pre-stressed concrete girder allow for longer span lengths.

The use of concrete with a specified compressive strength of 14700 psi (101 Mpa) at 56 days permitted the use of AASHTO Type IV girders for a span of 157 ft. (47.9 m) on the North Concho River. U.S 67 and South Orient Railroad Overpass in San Angelo, Texas. A simple span length of 157 ft is impossible to achieve with normal strength concretes and a 54 in. (T-372-mm) depth girder. On multi span bridges, the use of longer girders results in fewer spans and fewer substructures.

In Colorado, a HSC bridge was used to replace a previous structure that carried Interstate 25 over Yalc Avenue in Denver. The previous structure consisted of a four span, cast in place T Girder Bridge with piers located in the median of Yalc Avenue and at each side of the roadway. The HSC Bridge used 10000 psi (69 Mpa) concrete and consisted of two spans in place of the original four spans. The use of HSC, in combination with adjacent box beams, met the requirements for longer spans while maintaining a shallow superstructure depth.

High strength concrete is also being used in bridge decks where durability is far more important than compressive strength. Consequently, performance requirements other than strength are being specified. For durability, performance can be measured using freeze thaw resistance, deicer scaling resistance, abrasion resistance or chloride permeability.

With bridges, there are additional costs associated with maintenance and repair. The use of HSC with its greater durability is likely to result in less maintenance and longer life. With the introduction of life cycle costing, the long term economic benefits are likely to more than offset the premium cost for initial construction.

2.2.3 OFFSHORE STRUCTURES

Since the beginning of 1970s concrete with compressive strength in excess of 6000 psi i.e. (41 Mpa) has been used in offshore structures.

High strength concrete is important in offshore structures as a means to reduce self-weight while providing strength and durability.

In 1948, the Gomar Beaufort Sea was placed in the Arctic. This exploratory drilling structure contains about 12000 cu yd (9200 cu m) of high strength lightweight concrete with unit weights of about 112.1 lb/ft^3 (1.79 Mg/m^3) and 56 days compressive strength of 9000 psi (62 Mpa).

The structure also contains about 6500 cu yd (5000 cum) of high strength normal weight concrete with unit weights of about 145 lb/ft^3 (2.32 Mg/m^3) and 56 days compressive strength of about 10000 psi.

2.3 MATERIALS FOR HIGH STRENGTH CONCRETE

High Strength Concrete is prepared through a careful selection of each ingredient. The performance and quality of each ingredient becomes critical as the targeted strength increases. The basic materials used to produce day-to-day concrete such as cement, aggregates, water and admixtures are also used to produce high strength concrete. The most noticeable differences will be increased cement contents, reduced water contents and increased use of chemical and mineral admixtures. It is necessary to get the maximum performance out of all of the materials involved in producing high strength concrete. For convenience, the various materials are discussed separately below. However, it must be remembered that prediction with any certainty as to how they will behave when combined in a concrete mixture is not feasible, particularly when attempting to make high strength concrete. Thus, the culmination of any mix design process must be the extensive testing of trial mixes.

2.3.1 ADMIXTURES

Definition

Admixtures are the ingredients in concrete other than Portland cement, water, and aggregate those are added to the mixture immediately before or during mixing. Admixtures can also be defined as the ingredients in concrete other than

Portland cement, water, and aggregate those are added to the mixture immediately before or during mixing.

Admixtures are classified as per the purpose for which they are used in concrete.

Introduction

The idea to introduce chemicals to improve properties of concrete is not new. Hundreds of years before Christ, blood or eggs were used to improve concrete property. With the times, development in this field has led to the remarkable achievements in the field of concrete technology and a successful business.

Chemical admixtures are the ingredients in concrete other than Portland cement, water, and aggregate that is added to the mix immediately before or during mixing. Producers use admixtures primarily to reduce the cost of concrete construction; to modify the properties of hardened concrete; to ensure the quality of concrete during mixing, transporting, placing, and curing; and to overcome certain emergencies during concrete operations.

The effectiveness of an admixture depends on several factors including: type and amount of cement, water content, mixing time, slump, and temperatures of the concrete and air. Sometimes, effects similar to those achieved through the addition of admixtures can be achieved by altering the concrete mixture-reducing the water-cement ratio, adding additional cement, using a different type of cement, or changing the aggregate and aggregate gradation.

Five Functions

There are five distinct classes of chemical admixtures: air-entraining, water-reducing, retarding, accelerating, and plasticizers (super plasticizers). All other varieties of admixtures fall into the specialty category whose functions include corrosion inhibition, shrinkage reduction, alkali-silica reactivity reduction, workability enhancement, bonding, damp proofing, and coloring.

Air-entraining admixtures

These are used to purposely place microscopic air bubbles into the concrete, and are discussed fully in "Air-Entrained Concrete."

Water-reducing admixtures

Water reducing admixtures usually reduce the required water content for a concrete mixture by about 5 to 10 percent. Consequently, concrete containing a water-reducing admixture needs less water to reach a required slump than the concrete without any super plasticizer. The treated concrete can have a lower water-cement ratio. This usually indicates that a higher strength concrete can be produced without increasing the amount of cement..

Retarding admixtures

This type of admixtures slows the setting rate of concrete, andis used to counteract the accelerating effect of hot weather on concrete setting. High temperatures often cause an increased rate of hardening which makes placing and finishing difficult. Retarders keep concrete workable during placement and delay the initial set of concrete. Most retarders also function as water reducers and may entrain some air in concrete.

Accelerating admixtures

Accelerating admixtures increase the rate of early strength development; reduce the time required for proper curing and protection, and speed up the start of finishing operations. Especially in cold water, these admixtures are very useful in modifying the concrete properties.

Super plasticizers

These are also known as plasticizers or high-range water reducers (HRWR).They reduce water content by 12 to 30 percent and can be added to concrete with a low-to-normal slump and water-cement ratio to make high-slump flowing concrete. The effect of super plasticizers lasts only 30 to 60 minutes, depending on the brand and dosage rate, and is followed by a rapid loss in workability. As a result of the slump loss, super plasticizers are usually added to concrete at the jobsite.

Corrosion-inhibiting admixtures

These are used to slow corrosion of reinforcing steel in concrete. Corrosion inhibitors can be used as a defensive strategy for concrete structures, such as marine facilities, highway bridges, and parking garages, that will be exposed to high concentrations of chloride. Other specialty admixtures include shrinkage-reducing admixtures and alkali-silica reactivity inhibitors. The shrinkage reducers are used to control drying shrinkage and minimize cracking, while ASR inhibitors control durability problems associated with alkali-silica reactivity

Different types of water reducer according to ASTM C494 standard are given in the following table.

Different Types of Water Reducer

Table 2.1

TYPE	FUNCTION	EFFECTS
A	**Water reducer**	**Reduce water demand at least 5%.**
B	**Reducer**	**Retard setting time.**
C	**Accelerator**	**Accelerate setting and early strength development**
D	**Water reducer and retarder**	**Reduce water (minimum 5%) and retarder set**
E	**Water reducer and accelerator**	**Reduce water demand (minimum5 %)**
F	**Water reducer (high range)**	**Reduce water demand (minimum 12%)**
G	**Water reducer-high range and Retarder**	**Reduce water demand (minimum l2%) and retard set.**

2.3.1.1FACTORS AFFECTING EFFECTIVENESS OF ADMIXTURES

.The effectiveness of an admixture depends upon such factors as type, brand, and amount of cement; water content; aggregate shape, gradation and proportions; mixing time; slump; and temperature conditions and air content. Concrete should be workable, finish able, strong, durable, watertight, and wear resistant. For ordinary concrete these qualities can often be obtained easily and economically by the selection of suitable materials rather than resorting to admixtures. However for HSC, it becomes necessary use admixtures like super plasticizers. The major reasons for using admixtures are:

a. To reduce the cost of concrete construction.

b. To achieve certain properties in concrete more effectively than by other means.

c. To ensure the quality of concrete during the stages of mixing, transportation, placing, and curing in adverse conditions.

2.3.2 PORTLAND CEMENT

The type and quality of the cement to be used in HSC requires special attention even after addition of additional cementing materials like fly ash and silica fume. Different brands of given ASTM type of cements do not perform in the same way when making high strength concrete. Some perform very well in terms of final strength, but very poorly in terms of performance behavior. It is very difficult to maintain their workability long enough to place them in the field economically and satisfactorily with high degree of reliability and uniformity. Others perform very well in terms of performance; their slump loss within the first 1 or 2 hours is minimal. However, they perform very poorly in terms of compressive strength. High strength concretes have been produced successfully using cements meeting the *ASTM standard specification C150* for Types I, II and III Portland cements. While choosing Portland cement for use in high strength concrete, it is necessary to look carefully at the cement fineness and chemistry.

2.3.2.1 FINENESS

Hydration starts at the surface of the cement particles therefore, it is total surface area of cement that represents the material available for hydration. Fineness of cement affects heat released and the rate of hydration. Greater cement fineness increases the rate at which cement hydrates and thus accelerates strength development. An increase in fineness increases the amount of gypsum required for proper retardation, as in finer cement more C3A is available for early hydration. The requirement of water for preparation of a paste of standard consistence for finer cements is greater. But conversely an increase in fineness of cement slightly improves the workability of a concrete mix. Blaine fineness data is along with allowable compound composition of different types of cement is given.

2.3.2.2 CHEMICAL COMPOSITION OF THE CEMENT

High C3A contents generally leads to rapid loss of flow in the fresh concrete, and as a result high C3A contents should be avoided in cements used for high strength concrete. Aitcin has shown that the C3A should primarily in its cubic, rather than in its orthorhombic, form. Further, Aitcin suggests that attention must be paid not only to the total amount of SO3 in the cement, but also to the amount of soluble sulfates. Thus, the degree of sulfurization of the clinker is an important parameter. Some results are mentioned in table 2.2

Table 2.2**Chemical Composition of cement**

Test	Unit	Results	Limits	Comp	Unit	Results	Limits
SiO_2	%	21.13	No Limits	C_3S	%	43.68	No Limits
$A1_20_3$	%	5.70	No Limits	C_25	%	27.64	No Limits
Fe_2O_3	%	3.27	No Limits	C_3A	%	6.07	No Limit
CaO	%	62.42	No Limits	C_4AF	%	9.94	No Limits
MgO	%	2.25	<4.0				
$S0_3$	%	2.89	<3.0				
Na_2O	%	0.17	No Limits				
K_20	%	0.93	No Limits				
Others	%	1.81	<4.0				

2.3.2.3 COMPRESSIVE STRENGTH

Compressive strength as specified by ASTM C 150 is that obtained from tests made and cured in a prescribed manner using standard sand. ASTM C 150 sets only a minimum strength requirement that is exceeded comfortably by most manufacturers. Therefore, it should not be assumed that two types of Portland cement meeting the same minimum requirements would produce the same strength of mortar or concrete without modification of mix proportions. In general, cement strengths (based on mortar-cube tests) cannot be used to predict concrete strengths with a great degree of accuracy because of the many variables in aggregate characteristics, concrete mixtures, and construction procedures. The strength uniformity of cement from a single source may be determined by the procedures outlined in ASTM C 917.

2.3.2.4 SETTING TIME AND CONSISTENCY

Initial set of cement paste must not occur too early and final set must not occur too late. The setting times indicate the nature of hydration of the paste. Gypsum in the cement regulates setting time. Setting time is also affected by cement fineness, water-cement ratio and admixtures. Consistency refers to the relative mobility and ability to flow of a freshly mixed cement paste. During cement testing, pastes are mixed to normal consistency as defined by a penetration of 5 ± 1 mm of the Vicat-plunger from the bottom.

CHOICE OF CEMENT FOR HSC

The contemporary practices in making HSC are mostly based on the use of normal Portland cement. Unless high initial strength is the objective, such as in pre-stressed concrete, there is no need to use Type III cement. Furthermore within given cement type, different brands will have different strength development characteristics because of the variation in compound composition and fineness that are permitted by ASTM C 150.

The cement should have at-least following characteristics: -

a. Cement should be uniform and fresh as much as possible. To ensure uniform results tricalcium silicate content should not vary more than 4%, the ignition loss by more than 0.5 % and the fineness by more than 19.736 yds/lb.
b. To produce HSC of uniform consistency following physical properties should be ensured:-

Maximum Blaine Value	210.5um
7 Day mortar cube strength	- 4200 psi
Mortar air content	7-10 %

c. Sulphate ($S0_3$) level should be maintained at optimum with variations limited to ± 0.20 percent. When high temperature rise is expected to be a problem, a Type II, low-heat of hydration cement can be used, provided it meets the strength requirements.
d. By study and trials; cement-admixture optimization and compatibility be determined.
e. High C_3 A in Portland cement should be avoided because on reaction with free sulphates present in super plasticizing admixtures it causes abnormal stiffening or slump loss.
f. Silicates C_3 S and C_2 S are the heart of the cement past, ideal % of these ingredients should be 75%.

2.3.3AGGREGATES FOR HSC

Since a primary consideration is to keep the water requirement as low as possible, it should be obvious that only well-graded, fine and coarse aggregates should be considered for use.

"Both fine and coarse aggregates used for high-strength should meet the requirements of ASTM C33".

2.3.3.1 THE SEARCH FOR STRONG AGGREGATES

In Normal Strength Concrete aggregate choice does not influence on strength. However, in HSC aggregate may become the weakest zone to fail as the cement paste and the transition zone are made very strong? The aggregates used to make high strength concrete are natural sand and gravel or crushed aggregates. The strength of the natural aggregates depends on the nature of the parent rock, which was reduced to its present size through natural weathering processes. As a result, nothing can be done to improve the strength of natural aggregates. Using crushed aggregates to make high strength concrete leads to processing in which particles contain the minimum possible concentration of weak elements. In selecting aggregates, a fine- textured strong rock that can be fractured in particles containing the minimum amount of micro cracks should be selected. This rock can be single rock material, such as limestone, dolomite limestone and syenite, or polyphasic material such as granite. Rocks containing weak cleavage planes or severely weathered particles must be avoided.

2.3.3.2 COURSE AGGREGATE

The choice of coarse aggregate for the purpose of being used in HSC mix should be practiced keeping in view its shape and surface texture. Aggregate should be hard and strong. Shape, size ,surface texture along with the mineralogy of the aggregate, control the bond of paste to aggregate and therefore play an important role in the strength producing qualities in HSC. The optimum maximum size of coarse aggregate for higher-strength ranges depends on relative strength of the cement paste, cement-aggregate bond, and strength of the aggregate particles. However, typical parameters of grading for making high strength concrete given in ACI publication are beneficial for selection of maximum size and grading of aggregate.

Many studies have shown that for optimum compressive strength with high cement content and low water-cement ratios the maximum size of coarse aggregate should be kept to a minimum, at ½” or 3/8”. Smaller aggregate sizes are also considered to produce higher concrete strength because of less severe concentrations of stress around the particles, which are caused by differences between the elastic modulus of the paste and the aggregate. It has been seen that crushed stone produces higher strength than rounded gravel. The ideal aggregate should be clean, cubic, angular, 100 percent crushed aggregate with a minimum of flat and elongated particles.

2.3.3.3 FINE AGGREGATES

In conventional concrete fine aggregate has a primary function in providing workability. Sands with a fineness modulus (FM) around 2.5 produce concrete with very "sticky" characteristics, which result in loss of workability and higher water demands. Sands with a FM around 3.0, which are considered coarse under normal conditions, provide the best workability and highest compressive strength.

The influence of sand particle shape and surface texture appears to have at least as great an effect on mixing water and compressive strength of concrete as those of coarse aggregate mix. Fine aggregates with a rounded particle shape and smooth texture have been found to require less mixing water in concrete and for this reason are preferable in High Strength Concrete. As per National Crushed Stone Association (USA) the sand gradation had no significant effect on early strength but that “at later ages and consequently higher levels of strength, the gap-graded sand mixes exhibited lower strength than the standard mixes.

2.3.3.4 <u>MIXING WATER</u>

Water for mixing and curing concrete should be reasonably clean and free from objectionable quantities of organic matter, silt, and salts. Water quality for NSC and HSC is almost supposed to be same. Water should be free from impurities. Excessive impurities in mixing water may not only affect setting time and concrete strength, but also cause efflorescence, staining, and corrosion of reinforcement, volume instability, and reduced durability. Some of the undesirable effects of certain impurities in the water are as under: -

a. The maximum limit of turbidity should be 2000 parts per million(ppm). If clear water does not taste brackish or salty it can be generally used for mixing and curing of concrete without testing.
b. Water that is apparently hard, or tastes bitter, may contain highSulphate concentrations and should be analyzed.
c. Experience and tests have shown that water containing sulphate concentrations of less than 1% can be safely used. Ordinary salt (sodium chloride) in concentrations of 3.5% may reduce concrete strength 8 to 10 % but may produce no other deleterious effects.
d. Highly carbonated mineral water may produce substantial reduction in strength

2.3.4 SILICA FUME

Introduction

The silica fume also called micro silica, is used in concrete as a mineral admixture, especially in the production of high strength concrete. Usually its colour is grey.

American concrete institute (ACI) defines silics fume as: "Very fine non crystalline silica produced in electric arc furnaces as by product of production of elemental silicon or alloys containing silicon"

The silica fume particles are spherical with diameter ranging between 0.1-0.2 micrometer and specific surface area of 20-23m^2/g (the specific surface area of cement is 0.3-0.35m^2/g). Silica fume is available in three different forms: dry powder, dry densified powder and slurry, the most common being the densified powder.

Brief History of Silica Fume Concrete

The first known tests on the silica fume concrete were in the early 1950's at the *Norwegian Institute of Technology*. At the same time silica fume concrete was employed in a tunnel project in Oslo alum shale region. However the world-wide investigation and practical use of silica fume was not started until 1970s when a large amount of silica fume was collected as results of introduction of far stricter environment legislation in many countries. When silica fume was first introduced in concrete industry as cement replacement and was usually for economic purpose. As research work progressed and with better knowledge about silica fumes concrete, also because the increased price, silica fume is now often used as an effective additive to produce a better quality concrete. High strength concrete using silica fume up to 300 Mpa have been used in some countries; calcium nitrate attack was effectively reduced by applying silica fume in concrete fertilizer storage silos; silica fume concrete has been used in repairing a dam stilling basin for suitable abrasion erosion resistance; silica fume has been employed as essential additives to prevent alkali-silica reaction.

2.3.4.1 The Influence of Silica Fume on the Properties of Fresh Concrete

Silica fume has been used as an addition to concrete unto 20 % by weight of cement. With an addition of 20%, the potential exists for very strong and brittle concrete. The following are the effects of silica fume on the properties of fresh concrete:-

a. **Effects on Workability**

The most immediate and visible effect of the addition of silica fume in the concrete is a reduction in the workability

b. **Effects on Water Requirement**

Silica fume added to concrete by itself increases water demand. This problem can be easily compensated for by using high range water reducers.

c. **Effects on Consistency and Bleeding**

Concrete in cooperating more than 10% silica fume become sticky; in order to enhance workability, the initial slump should be increased. It has been found that silica fume reduces bleeding because of its effect on performance properties.

d. **Hydration.**

Heat of hydration generated in silica fume concrete is slightly higher than that of plane cement concrete.

e. **Segregation.**

Improves the cohesiveness, and reduces the segregation of concrete

2.3.4.2 The Influence of Silica Fume on the Properties of HardenedConcrete

The particulars advantage of using silica fume as a very fine and reactive pozzolana for use in high strength concrete is recognized. By using silica fume it has been shown that it is possible to make workable concrete with a compressive strength in the range of 100 – 150 MPa. Following are the salient properties of hardened concrete that are affected by the silica fume:-

a. **Effects on Strength of Hardened Concrete.** Silica fume has been successfully used to produce very high strength, low permeability and chemically resistant concrete. Addition of silica fume by itself, with other factors being constant, increases the concrete strength. In corporation of silica fume into a mixture with high range water reducer also enables the use of low water / cementitious materials ratio then may have possible otherwise.

b. **Modulus of Rupture.** The modulus of rupture of silica fume concrete is usually either about the same as or somewhat higher than that of conventional concrete at the same level of compressive strength.

c. **Effects on Permeability of Hardened Concrete.** It has been shown by several researchers that addition of silica fume to concrete reduces its permeability. This reduction is primarily the result of the increased density of the matrix due to the presence of silica fume.

d. **Effects on Freeze–thaw Durability of Hardened Concrete.** Air-void stability of concrete incorporating silica fume test results indicated that the use of Silica Fume has no significant influence on the production and stability of the air-void system. Freeze-thaw testing (ASTM C 666) on silica fume concrete showed acceptable results; the average durability factor was greater than 99% (Luther and Hansen 1989; Ozyildirim 1996).

Chemical composition of Silica Fume

Table 2.3

S.No	Description	%age
1	SiO_2	92
2	Al_2O_3	0.6
3	Fe_2O_3	1.0
4	CaO	0.4
5	MgO	1.5
6	K_2O	0.8
7	Na_2O	0.5

Physical Properties of Silica Fume

Table 2.4

Particle size (typical)	<4 x 10^8 in.
Bulk density (as produced)	8 to 27 lb/ft^3
(Slurry)	11 to 12 lb/gal
(densified)	30 to 45 lb/ft^3
Specific gravity	2.2
Surface area (BET)	60,000 to 150,000 ft^2 /lb

Comparison of Chemical & Physical Characteristics of Silica Fume,Fly Ash and Cement

Table 2.5

Description	**Silica Fume**	**Fly Ash**	**Cement**
SIO2 content	85 – 97	45 – 48	20 – 25
Surface Area m^2/kg	17000–30000	400 – 700	300 – 500
Pozzolanic Activity (with cement, %)	120 – 210	65 – 110	-
Pozzolanic Activity (with lime, MPa)	1200 – 1660	800 – 1000	-

How Silica Fumes works: Mechanism

The interaction between the silica fume and the cement particles can be classified as physical and chemical. The former, which are called the “micro filler effect”, consists on the filling of the spaces between the cement particles by the silica fume. The later called the pozzolanic effect, follows from the reaction of the silica fume with portlandite produced by the hydration of the silicates, giving a silicate hydrate gel *(i.e. C-S-H):*

$$SiO_2 + Ca(OH)_2 + H_2O = CaO.SiO_2.H_2O$$

Silica fume affects the properties of concrete in the fresh and hardened states. In the fresh state, its incorporation increases water demand due to high surface area. Consequently, the workability of the concrete depends on the silica fume content. Studies showed that silica fume incorporation leads to decrease in the plastic viscosity and yield stress. On the other hand, the incorporation of the silica fume increases the stability (i.e. bleeding and segregation of the fresh concrete).

The microstructure of the hardened cement paste is significantly modified by the incorporation of the silica fume, producing a fine pore structure. The micro structure of the interfaces is also affected by the silica fume, leading to fewer portable crystals and denser interfaces.

The formation of the denser matrix and interfaces leads to significant increase in the strength of the concrete due to the incorporation of the silica fume. This is mainly produced by the micro filler effect. Finally the durability of concrete is improved due the significant decrease in the permeability, as well as reduction in the deterioration due to alkali- aggregate reactions. The decrease in the portlandite also contributes to the protection of the concrete from surface attack.

2.3.5 FLY ASH

Introduction:

It is an industrial waste and a material of pozzolanic characteristics occurring due to burning the pulverized coal in the thermal power plants. In the construction sector fly ash is used in the production of cement as an additive material in production of concrete instead of some of the cement or instead of some of the fine aggregate as base or sub base material in highway construction, as a filling materials in dams, in retaining walls and for the production of light construction materials.

(ACI Committee 1987, Erdogan 1997)

Compounds contained in Fly Ash:

1. SiO_2
2. Al_2O_3
3. Fe_2O_3
4. CaO
5. MgO
6. K_2O
7. Na_2O
8. SO_3
9. Cl^-
10. Free Lime

Classification of Fly Ash on the basis of gradation:

1. Fine ash
2. Medium ash
3. Coarse ash

Filler Effect of Fly Ash:

Fly ash as other pozzolanic materials affects the technical properties of cement mortar and concrete by its pozzolanic characteristics and filler effects. It is known that the filler effect of Fly Ash is more effective than the pozollanic characteristics when affecting the properties of concrete (Goldman & Bentur 1993; Aiqin et al 2003).

Fly ashes have pozzolonic activity because they contain surplus amount of silica , alumina and iron oxide; they have structures with very fine paricles and amorphous.

Strength effects of Fly Ash:

Strength of the concrete in which fly ash is used even upto 30 % of cement is lower at the early stages, however the strength increases in later stages after some years and the ultimate strength is higher. Increase in strength of concrete also depends on the type, fineness and usage ratio of Fly Ash. Type C contributes in gaining more early strength than type F (Erdogan 1997).

2.3.6 HIGH RANGE WATER REDUCERS

The properties of present-day concrete, as well as scope of its utilization, are influenced significantly by the incorporation of chemical admixtures, which have components of concrete. The most important in these admixtures, especially in high strength concrete technology, are probably the high range water reducers or super-plasticizers. A better understanding, therefore, of the effects of the super-plasticizer on the properties of concrete is essential for further improvement of its properties and behavior.

High strength concrete requires use of low water-cement ratio, which results in workability problems. This tendency becomes more pronounced when much higher strength is required and conventional concreting processes cannot sufficiently guarantee at high quality work. The normal water-reducing admixtures are derived from salts of sulfonated lignin, hydroxyl acid or hydroxylated polymers. Generally, it is possible to reduce the water content of a concrete mixture by 5 to 10% with normal dosage of admixtures. Water-reducing admixtures popularly known as super-plasticizers provided a solution to this problem.

For obtaining good workability and in turn high compressive strength, use of a super-plasticizer can result in a water demand of 25 to 35 percent. In consequence, the use of low *water/cement* ratio is possible so that very high strength concrete is achieved. Silica Fume, Fly Ash, Blast-furnace Slag and other pozzolanas can be used with super-plasticizer for partial replacement of cement to achieve higher strengths.

Some of the important features of super-plasticizers are as below:

a. Improved workability produced by super-plasticizers is of short duration and thus there is high rate of slump loss; the workability returns to become normal after 30-90 minutes. The plasticizers therefore should be added to the mix immediately prior to placing.

b. Super-plasticizers do not significantly affect the setting of concrete except in the case of cement with a very low C_3A content when there may be excessive retardation. Other long-term properties of concrete are not appreciably affected.

c. The use of super-plasticizers with an air-entraining admixture can sometime reduce the amount of entrained air and modify the air-void system.

d. The only real disadvantage of super-plasticizers is their relatively high cost, which is due to the expense involved in manufacturing a product with a high molecular mass.

CHAPTER -3

SURVEY AND SELECTION OF MATERIAL

3.1 CEMENT

Ordinary Portland cement, designated as Type-I from FAUJI cement Factory was used.

Initial and Final Setting Time

Initial and final setting time of the cement was calculated as per IS: 4031 (Part 5) -1988. Vicat apparatus conforming to IS: 5513 -1976 balance was used . Results are shown in Table 3.1.

Table 3.1

Setting Time	ASTM c 150 Limits	Result
Initial	≥ 45 mins	51 mins
Final	≤ 375 mins	273 mins

3.2 FINE AGGREGATE

A number of sieve analysis of locally available fine aggregates at Military College of Engineering reveal that among all sands, Lawrancepur sand has greater values of Finess Modulus. This sand has also been found to be free from most of harmful impurities. After conducting sieve analysis of sand it was found that sand was not well graded and its finess modulus was also less. Pan from concrete lab was added in different proportions to adjust the gradation and finess modulus of sand.

3.2.1SIEVE ANALYSIS

Sieve analysis was carried out according to BS 882:1973 to determine the grain size distribution and the fineness modulus. Fineness modulus indicates the relative fineness of aggregates. It is direct indication of quality of fine aggregates. The value of fineness modulus varies from 2.3 to 3.1, coarser the sand higher the FM. After mixing different proportions of pan we were finally reached to sand having FM of 2.84 which was just satisfactory for preparing HSC. The results are shown in table 3.2. The grading curve of the sand is shown in fig (a) which indicates it was well within the permissible limits.

Sieve Analysis of Fine Aggregate

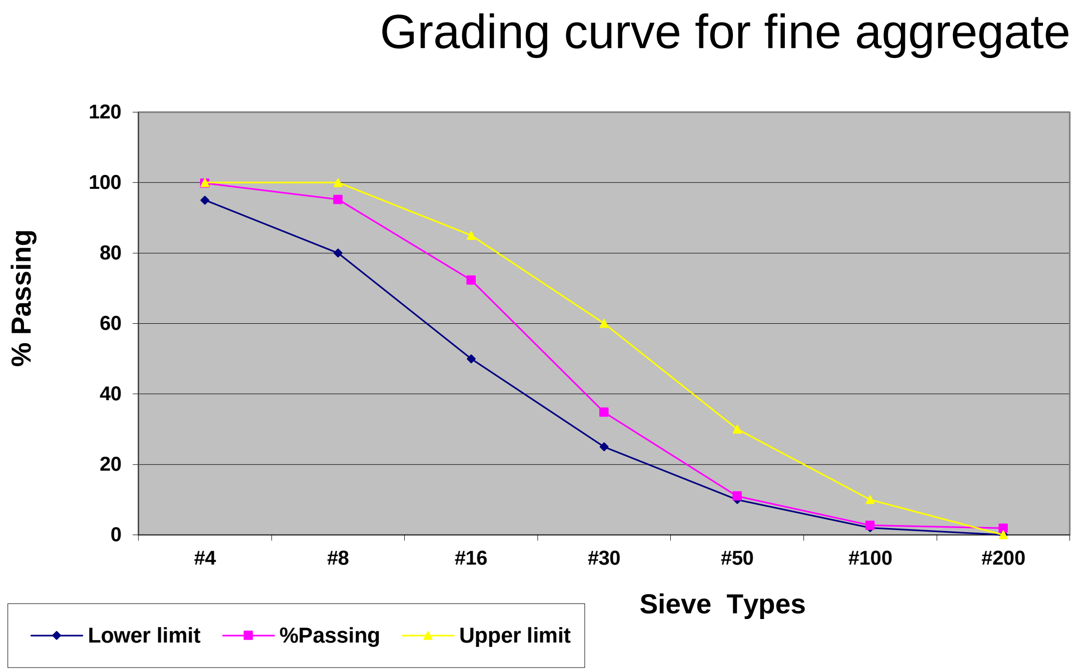
Origin: Lawrancepur

Fineness Modulus: 2.84

Table 3.2

Sieve	Mass (gm)	% Retained	Cumulative % Passing	ASTM limits	Cumulative % Retained
#4	2	0.2	99.8	95-100	0.2
#8	46	4.6	95.2	80-100	4.8
#16	229	22.9	72.3	50-85	27.7
#30	375	37.5	34.8	25-60	65.2
#50	238	23.8	11	10-30	89
#100	83	8.3	2.7	2-10	97.3
#200	18	0.8	1.9	--	98.1
Pan	12	1.9	0	--	100

FM = (0.2 + 4.8 + 27.7 + 65.2 + 89 + 97.3)/100 = 2.84



fig(a)

3.2.2 <u>SPECIFIC GRAVITY AND ABSORPTION</u>

While designing the mix we require water absorption and specific gravity of fine aggregates. Specific gravity and water absorption of fine aggregates were determined according to ASTM C128 and the results are given in table 3.3.

Table 3.3 <u>Specific Gravity and Water Absorption of Fine Aggregate</u>

Ser	Property	Result
1	Bulk specific gravity (Oven dry)	2.68
2	Water Absorption	1.25%

3.2.3 NATURAL MOISTURE CONTENT AND UNIT WEIGHT

Natural moisture content and unit weight of fine aggregates are other important values required for designing the concrete mix. Once specific gravity of fine aggregates is known unit weight can easily be calculated. Natural moisture content in lab was easily calculated by drying varying samples in oven for 24 hours. The results are shown in table 3.4.

Table 3.4

Ser	Property	Result
1	Natural moisture content	0.9 %
2	Unit weight (lb/cubic ft)	103

3.3 COARSE AGGREGATE

Coarse aggregate for the preparation of HSC plays vital role because with low w/c ratio failure of concrete begins from aggregate crushing. So selection of hard aggregate is very important for designing HSC. We reviewed data given in previous thesis on coarse aggregates from various queries of Pakistan. As HSC has not been attained importance in Pakistan, hard aggregate is not readily available. Data from the previous thesis on coarse aggregates from various hills is given in table 3.5.

<u>Test Data on coarse aggregate obtained from previous thesis review</u>

Table 3.5

SAMPLE	IMPACT Value %	CRUSHING Value %	ABRASION Value %	SPECIFIC GRAVITY
Kabul River	12.05	-	17.00	-
Nazimpur	20.05	-	18.05	-
Margala	22.05	-	20.00	-
Wah	23.00	-	21.05	-
Hassanabdal	21.00	-	15.00	-
Margala	16.05	-	21.05	-
Margala	23.00	-	21.08	-
Dina	16.34	26.02	26.08	02.53
Attock	15.08	26.01	24.06	02.07
Peshawar	19.42	26.08	28.02	02.75
Dina	27.08	-	18.05	-
Attock	21.00	-	20.00	-
Riverjehlum (mangala)	21	-	16.03	-
Margala	17.08	28.94	-	02.68
Sargodha	12.05	19.39	-	02.07
Dina	17.05	28.94	-	02.68

Hence the review of previous thesis revealed that the aggregate from *Kirana hills of Sargodha* was the strongest available in Pakistan. During the study it was found that almost all the crush plant were not producing hard and strong aggregates. It was probably because, strong stone requires huge amount of labor and machine efforts, which makes the production of coarse aggregates uneconomical for the producers.

Review of previous thesis for coarse aggregate was aimed at obtaining a hard and tough material from the family of igneous rocks having excellent physical properties, such as low impact and crushing value, high specific gravity unit weight, gradation and water absorption. The aggregate found in Sargodha i.e. Kirana Hills met these requirements therefore it was finally selected for the preparation of HSC.

Kirana hills are located about 10 km south of Sargodha. These hills are mainly comprised of crush stone such as quartzite, slates, lava flows and other rocks. The toughest stone was found in the hills Chak-111.

The crush was collected in three different sizes i.e. 1/2, 3/8, 3/16. Aggregates of various sizes were mixed in number of proportions to reach at aggregates with optimum gradation.

3.3.1 GRADING

Grading or particle size distribution of aggregate is determined by a sieve analysis. The grading affects the relative aggregate proportions as well as cement and water requirements, workability, porosity and shrinkage of concrete. Variations in grading may seriously affect the uniformity of concrete from one batch to another. Sieve analysis of the coarse aggregate was carried out as per procedure laid down in BS and the results are shown in table. Grading curve for the coarse aggregate is also shown in table 3.6 and fig (b), which is well within the specified boundaries.

Grading of Coarse Aggregate

Table 3.6

S.No	Sieve Size(inches)	Weight Ret (grams)	ASTM Limits	%Retained	Cum %Passing
1	3	-	-	-	100
2	2½	-	-	-	100
3	2	-	-	-	100
4	1½	-	-	-	100
5	1	-	-	-	100
6	¾	-	-	-	100
7	½	160	90-100	8	92
8	⅜	1060	30-60	53	39
9	3/16	770	0-10	38.5	0.5
10	Pan	10	--	0.5	--
Total		2000			

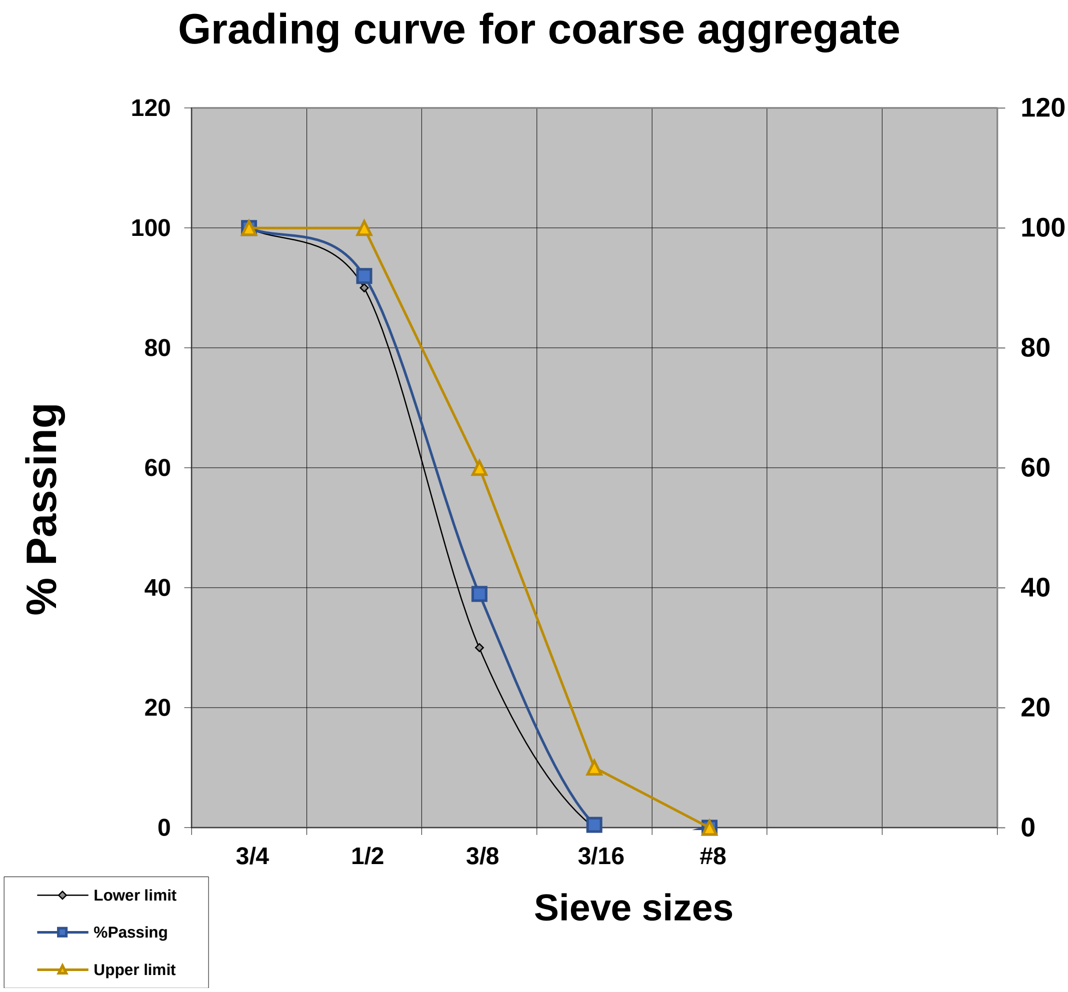


Fig (b)

3.3.2 <u>SPECIFIC GRAVITY AND ABSORPTION</u>

All the aggregates are porous with a varying degree and accordingly differ in specific gravity and absorption. Weaker stones have lower specific gravity and higher absorption. These two parameters are basic indicators of the quality of the aggregates and may form the basis for acceptance or rejection. Normal range of specific gravity is from 2.4 to 2.9. The specific gravity of coarse aggregate was found by the method given in ASTM C 127–81. Specific gravity was found to be 2.70 of Sargodha. This shows that the Sargodha crush is strongest available.

Absorption is a measure of porosity. Porosity of concrete aggregate affects very important properties of concrete such as permeability, absorption, resistance to freeze-thaw and abrasion. More porous aggregates will absorb more water in specified time (24 hrs). Range of absorption values can vary from 0.1% to 2.0%. Good aggregates will normally have a value less than 1%. The absorption was found to be 0.99%.

3.3.3 <u>CRUSHING VALUE</u>

The most valuable property of concrete, i.e. compressive strength is related to the compressive strength of aggregate. Clearly the compressive strength of concrete can not exceed that of major part of aggregate contained therein. Crushing value was determined as per the procedure laid down in BS-812- 1967 and was found to be 10.54% for Sargodha. Properties of Coarse Aggregate are given in table 3.7:

Properties of Coarse Aggregate

Table 3.7

Ser	Property	Result
1	Bulk specific gravity Oven Dried	2.70
2	Water absorption%	0.99
3	Crushing value %	10.54
4	Impact value % (Exceptionally Strong)	10.5
5	Abrasion %	17.74

3.4 WATER

Risalpur water was used throughout this research work.

3.5Admixtures Used

The admixture used was bought from IMPORIENT CHEMICALS (PVT) LTD Islamabad. The commercial name of the admixture was Chemrite NN.

3.5.1 Function

According to the manual provided by the company it has following two functions:

- High range water reducer
- Accelerator

3.5.2 Dosage

According to the manual the permitted consumption range of the admixture is 0.6 to 3 % by weight of cement.

3.5.3 ASTM Category

It complies with ASTM C-494, types A and F.

3.6 Fly Ash

We bought fly ash from Olympia Chemicals Factory situated in Warcha. They use coal as fuel so they have fly ash as a byproduct. OCL is the second largest producer of Soda Ash and Sodium Bicarbonate in Pakistan. It has started commercial production in 2000 with approximately 50,000 Tons annually and now it has reached a production capacity of 150,000 tons of Soda Ash and 15,000 tons of Sodium Bicarbonate annually. It was class F Fly Ash and it was brick red in colour due to presence of iron as impurity.

3.7 Silica Fume

It was also bought from IMPORIENT CHEMICALS (PVT) LTD Islamabad. It was in finely divided powdered form. According to the manual provide it complies with the ASTM C 1240

Chapter No 4

HIGH STRENGTH CONCRETE, MIX DESIGN AND CASTING

4.1 INTRODUCTION

Concrete mix design is the science of deciding relative proportions of ingredients of concrete, to achieve the desired properties in the most economical way.

ACI 211.1-91, Reapproved 2009, states: "Concrete is composed principally of aggregates, Portland cement, and water, and many contain other cementations materials and/or chemical admixtures. It will contain some amount of entrapped air and may also contain purposely entrained air obtained by use of admixture or air-entraining cement. Chemical admixtures are frequently used to accelerate, retard, improve workability, reduce mixing water requirements, increase strength, or alter other properties of the concrete. The selection of concrete proportions involves a balance between economy and requirements of place ability, strength, durability, density, and appearance."

4.2 SCOPE

This work is limited to high-strength concrete produced using conventional materials and production methods. Consideration of silica fume and ground granulated blast furnace slag (GGBFS) is beyond the scope of this document. ACI Committee 234, Silica Fume in Concrete, is developing information on the use of silica fume for a committee report. Currently, silica fume and GGBFS suppliers, as well as experienced concrete suppliers, represent the best source of proportioning information for these materials.

High-strength concrete is defined as concrete that has a specified compressive strength of 6000 psi or greater. The guide is intended to cover field strengths up to 12,000 psi, although greater strengths may be obtained

4.3 MIXTURE PROPORTIONING

Mix proportioning is the process of determining the quantities of concrete ingredients that meet the mix design criteria.

The guide for proportioning high-strength concrete mixtures is applicable to normal weight, non-air entrained concrete having compressive strengths between 8000 psi fc’.When proportioning high-strength concrete mixtures, the basic considerations are still to determine the ingredient quantities required to produce a concrete with the desired plastic properties (workability, finish ability, etc.) and harden (strength, durability etc.) at the lowest cost. Proper proportioning is required for all materials used shown in table 4.1:

Recommended slump for concretes with and without HRWR

Table 4.1

Concrete	Slump
Using HRWR	2 to 4 in
Without HRWR	1 to 2 in

Adjust slump to that desired in the field through the addition of HRWR.

The procedure described in ACI 211.1 for proportioning normal strength concrete is similar to that required for high-strength concrete. The procedure consists of a series of steps, which when completed provides a mixture meeting strength and workability requirements based on the combined properties of the individually selected and Proportioned components. However, in the development of a high-strength concrete mixture, obtaining the optimum proportions is based on a series of trial batches having different, proportions and contents of materials.

Completion of the following steps will result in a set of adjusted high-strength concrete laboratory trial proportions. These proportions will then provide the basis for field testing concrete batches from which the optimum mixture proportions may be chosen.

4.3.1 DESIGN STEPS (ACI 211.4R-93)

Step 1. Select slump and required concrete strength

Table 4.1

Concrete	Slump
Using HRWR	2 to 4 in
Without HRWR	1 to 2 in

Step 2. Select maximum size of aggregate

<u>Table 4.2</u>

Concrete Strength	Aggregate Size
< 9000 psi	**¾ to 1 in**
>9000 psi	**3/8 to1/2 in**

Use sand with a FM of 2.5 to 3.2

<u>Table 4.3</u>

Maximum size	3/8	½	¾	1
Volume	**0.65**	**0.68**	**0.72**	**0.75**

Step 3. Select optimum coarse aggregate content

Weight of the Coarse Aggregate Content=% × DRUW × 27

Step 4. Estimate mixing water and air contents

<u>Table 4.4</u>

Slump In	Mixing water (lbs/yd^3)			
	Maximum Size Coarse Aggregate in			
	3/8	½	¾	**1**
1 to 2	310	295	285	**280**
2 to 3	320	310	295	**290**
3 to 4	330	320	305	**300**
Air content	**3**	**2.5**	**2**	**1.5**
(With HRWR)	**(2.5)**	**(2.0)**	**(1.5)**	**(1.0)**

$$Void\ content,\ V\% = \left(1 - \frac{Oven\ dried\ rodded\ unit\ weight}{Bulk\ specific\ gravity \times 62.4}\right) \times 100$$

$$Mixing\ water\ adjustment = (V - 35) \times 8$$

$$Adjustment\ for\ absorption\ of\ aggregate = (Absorption - moisture) \times 0.8 \times Wt/100$$

Step 5. Select w/c

Table 4.5

Field Strength (f'_c)		**W/C**			
		Maximum size coarse aggregate in			
		3/8	½	¾	**1**
7000	28 days	.50	.48	.45	**.43**
	56 days	.55	.52	.48	**.46**
8000	28 days	.44	.42	.40	**.38**
	56 days	.48	.45	.42	**.40**
9000	28 days	.38	..36	.35	**.34**
	56 days	.42	.39	.37	**.36**
10,000	28 days	.33	.32	.31	**.30**
	56 days	.37	.35	.33	**.32**
11,000	28 days	.30	.29	.27	**.27**
	56 days	.33	.31	.29	**.29**
12,000	**28 days**	**.27**	**.26**	**.25**	**.25**
	56 days	**.30**	**.28**	**.29**	**.26**

Step 6. Calculate content of cementations material

Cementations Content = Quantity of water / (W/C)

Step 7. First estimate of weight of fresh concrete:

Table 4.6

Nominal maximum size of aggregate (in)	**First estimate of concrete weight (lb/yd^3)**	
	Non air entrained concrete	Air entrained concrete
3/8	3840	3710
½	3890	3760
¾	3960	3840
1	4010	3850
1-1/2	4070	3910
2	4120	3950
3	4200	4040
6	4260	4110

Step 8. Proportion basic mixture

Weight of sand = 3890 - wt of cement - wt of coarse agg - wt of water

Silica fumes = 12% × weight of cement.

Fly ash = 12% × weight of cement.

Plasticizer = (0.75 to 2.5) % of weight of cement

MIX PROPORTIONS AND BATCH QUANTITIES

The guide for selecting proportions for high strength concrete is covered in the ACI Committee 211. The guidelines given in the above mentioned committee were followed to prepare five mix designs.The calculations and the batch quantities for the four mix designs are as under:

Mix proportion for 9,000psi

PURE CEMENT SAMPLE (no silica fume & fly ash)

Step 1. Select slump and required concrete strength

Slump used without HRWR = 2 in (Ref. Table 4.1 & 4.2)
Concrete Strength = 9,000 psi

Step 2. Select maximum size of aggregate

Nominal maximum size of the aggregate used = ½ in

Dry-rod unit weight = 103 lbs. $/ft^3$

Step 3. Select optimum coarse aggregate content (Ref. Table 4.3)

Weight of the Coarse Aggregate Content = % × DRUW × 27

= 0.68 × 103 × 27

= 1891 lbs.

Step 4. Estimate mixing water and air contents

Mixing water estimated = 300 lbs. /yd^3 **(**Ref. Table 4.4)

Air content = 2.0 %

Step 5. Select w/c

Water cementations ratio = 0.36 **(**Ref. Table 4.5)

Step 6. Calculate content of cementetious material

Cementatious Content = Quantity of water / (w/c)

= 300 / 0.36

= 833 lbs.

Step 7. Weight of fresh concrete

According to ACI table 6.3.7.1 **(**Ref. Table 4.6)

Weight of fresh concrete =3890 lbs.

Step 8. Proportion basic mixture

Weight of sand = 3890-833-300-1891

= 866 lbs.

Batch Quantities

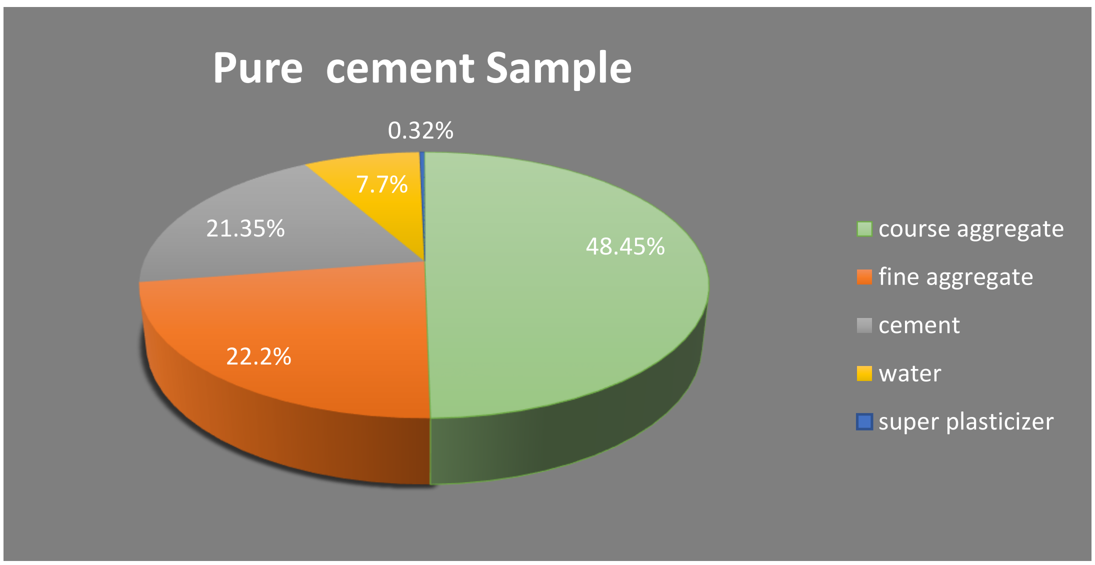
Batch quantities per cubic yard volume:

Mix ratio 1:1.18:2.58

Table 4.7

Materials	Weights(lbs.)
Cement	833
Sand	866
Coarse aggregate	1891
Water	300

Super plasticizer =1.5/100 * 833= 12.495lbs. /yd^3



Graph 4.1

Silica fume 12%

step 1. Select slump and required concrete strength

Slump used with HRWR = 2 in (Ref. Table 4.1 & 4.2)
Concrete Strength = 9,000 psi

Step 2. Select maximum size of aggregate

Nominal maximum size of the aggregate used **=** ½ in

Dry-rod unit weight = 103 lbs. $/ft^3$

Step 3. Select optimum coarse aggregate content **(**Ref. Table 4.3)

Weight of the Coarse Aggregate Content = % × DRUW × 27

= 0.68 × 103 × 27

= 1891 lbs.

Step 4. Estimate mixing water and air contents

Mixing water estimated = 300 lbs. $/yd^3$ **(**Ref. Table 4.4)

Air content = 2.0 %

Step 5. Select w/c

Water cementations ratio = 0.36 **(**Ref. Table 4.5)

Step 6. Calculate content of cementations material

Cementations Content = Quantity of water / (w/c)

= 300 / 0.36= 833 lbs.

Silica fume =12/100 × 833 =100 lbs.

Cement to be used = 833- silica fume

= 833-100

= 733 lbs.

Step 7. Weight of fresh concrete

According to ACI table 6.3.7.1

Weight of fresh concrete =3890 lbs.

Step 8. Proportion basic mixture

Weight of sand = 3890-733-300-1891-100

= 866 lbs.

Batch Quantities

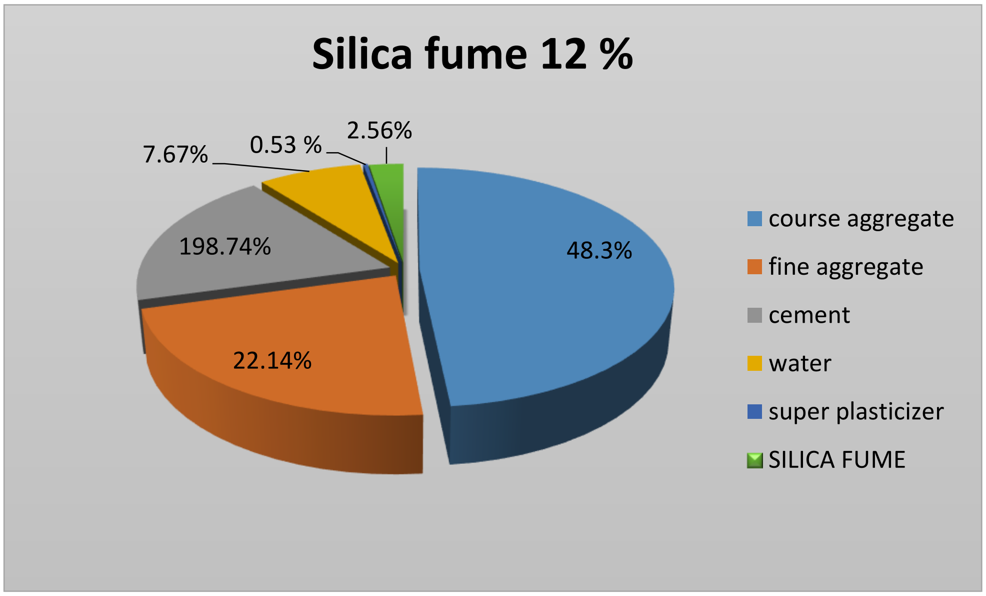
Batch quantities per yard cube

Mix ratio 1:1.18:2.58

Table 4.8

Materials	Weights(lbs.)
Cement	**733**
Sand	**866**
Coarse aggregate	**1891**
Water	**300**
Silica fume	**100**

Super plasticizer =2.5/100 * 833= 20.825lbs. /yd



Graph 4.2

Fly ash 12%

Step 1. Select slump and required concrete strength

Slump used with HRWR = 2 in (Ref. Table 4.1 & 4.2)
Concrete Strength = 9,000 psi

Step 2. Select maximum size of aggregate

Nominal maximum size of the aggregate used **=** ½ in

Dry-rodded unit weight = 103 lbs. /ft^3

Step 3. Select optimum coarse aggregate content **(**Ref. Table 4.3)

Weight of the Coarse Aggregate Content = % × DRUW × 27

= 0.68 × 103 × 27

= 1891 lbs.

Step 4. Estimate mixing water and air contents

Mixing water estimated = 300 lbs. /yd^3 **(**Ref. Table 4.4)

Air content = 2.0 %

Step 5. Select w/c

Water cementations ratio = 0.36 **(**Ref. Table 4.5)

Step 6. Calculate content of cementations material

Cementations Content = Quantity of water / (w/c)

= 300 / 0.36

= 833 lbs.

Fly ash =12/100 × 833 =100 lbs.

Cement to be used = 833- silica fume

= 833-100

= 733 lbs.

Step 7. Weight of fresh concrete

According to ACI table 6.3.7.1

Weight of fresh concrete =3890 lbs.

Step 8. Proportion basic mixture

Weight of sand = 3890-733-300-1891-100

= 866 lbs.

Batch Quantities

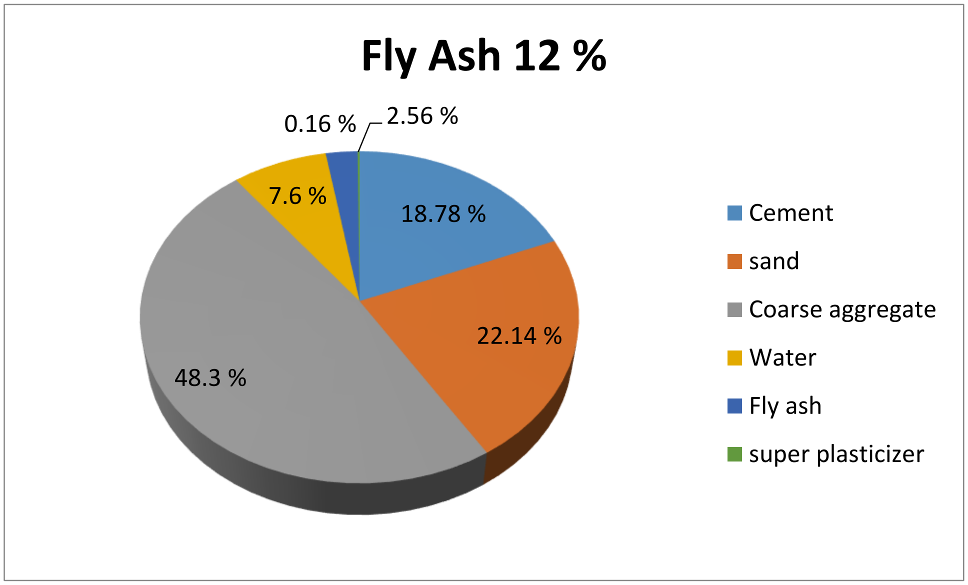
Mix ratio 1:1.18:2.58

Batch quantities per yard cube:

Table 4.9

Materials	Weights(lbs./yd^3)
Cement	**733**
Sand	**866**
Coarse aggregate	**1891**
Water	**300**
Fly ash	**100**

Super plasticizer =.75/100 * 833= 6.2475lbs. /yd^3



Graph 4.3

Silica fume 6% & Fly ash 6%

Step 1. Select slump and required concrete strength

Slump used with HRWR =2 in (Ref. Table 4.1 & 4.2)
Concrete Strength = 9,000 psi

Step 2. Select maximum size of aggregate

Nominal maximum size of the aggregate used **=** ½in

Dry-rodded unit weight = 103 lbs. /ft^3

Step 3. Select optimum coarse aggregate content **(**Ref. Table 4.3)

Weight of the Coarse Aggregate Content = % × DRUW × 27

= 0.68 × 103 × 27

= 1891 lbs.

Step 4. Estimate mixing water and air contents

Mixing water estimated = 300 lbs. /yd^3**(**Ref. Table 4.4)

Air content = 2.0 %

Step 5. Select w/c

Water cementations ratio = 0.36 **(**Ref. Table 4.5)

Step 6. Calculate content of cementations material

Cementations Content = Quantity of water / (w/c)

= 300 / 0.36 = 833 lbs.

Silica fume =6/100 × 833 =50lbs.

Fly ash = 6/100 × 833 =50lbs.

Cement to be used = 833- silica fume-fly ash

= 833-50-50

= 733 lbs.

Step 7. Weight of fresh concrete

According to ACI table 6.3.7.1

Weight of fresh concrete =3890 lbs.

Step 8. Proportion basic mixture

Weight of sand = 3890-733-300-1891-50-50

= 866 lbs.

Batch Quantities

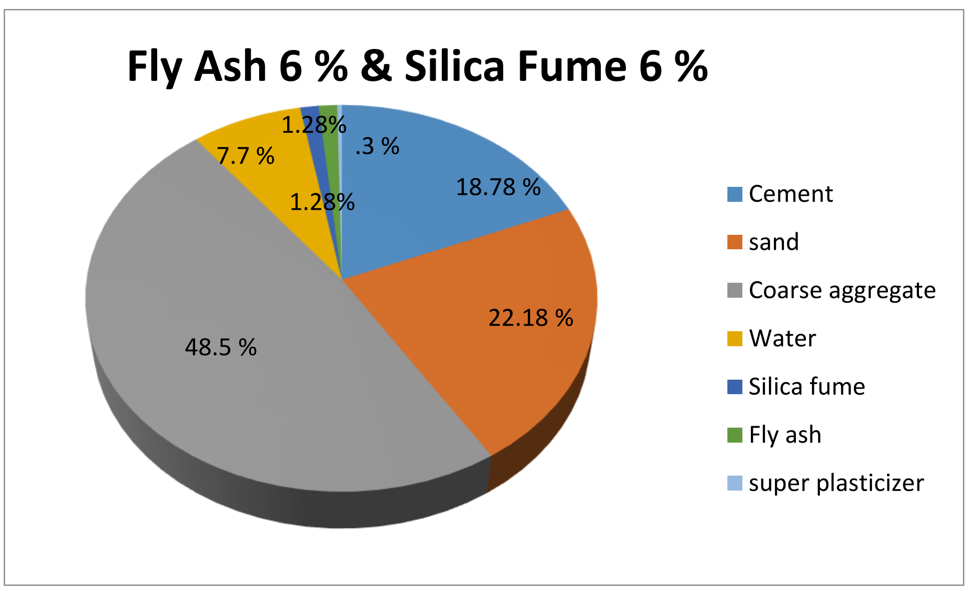
Batch quantities per yard cube

Mix ratio 1:1.18:2.58

Table 4.10

Materials	Weights(lbs./yd^3)
Cement	**733**
Sand	**866**
Coarse aggregate	**1891**
Water	**300**
Silica fume	**50**
Fly ash	**50**

Super plasticizer =1.5/100 * 833= 12.495lbs. /yd^3



Graph 4.4

Trial Mix PROPORTION

Pure cement

Table 4.11

	Step1	Step2 %	Step3 Lbs/yd^3	Step4 lbs/yd^3	Step5	Step6 Lbs/ yd^3	Step7 lb/yd^3	Step8 lb/ yd^3
fc' psi	9000							
Slump	2 in							
Agg %		0.68						
Wt of Agg			1891					
Water				300				
Air				2.0%				
w/c					0.36			
Cement						833		
Fresh concrete							3890	
Sand								866

SILICA FUME 12%

Table 4.12

	Step1	Step2 %	Step3 lb/ yd^3	Step4 lbs/yd^3	Step5	Step6 lb/ yd^3	Step7 lb/yd^3	Step8 lb/ yd^3
fc' psi	9000							
Slump	2 in							
Agg %		0.68						
Wt of Agg			1891					
Water				300				
Air				2.0%				
w/c					0.36			
Cement						733		
Slica fume 12%						100		
Fresh concrete							3890	
Sand								866

FLY ASH 12%

Table 4.13

	Step1	Step2 %	Step3 lb/ yd³	Step4 lbs/yd³	Step5	Step6 lb/ yd³	Step7 lb/ yd³	Step8 lb/ yd³
fc' psi	9000							
Slump	2 in							
Agg %		0.68						
Wt of Agg			1891					
Water				300				
Air				2.0%				
w/c					0.36			
Cement						733		
Fly ash 12%						100		
Fresh concrete							3890	
Sand								866

SILICA FUME 6% & FLY ASH 6%

Table 4.14

	Step1	Step2 %	Step3 lb/ yd^3	Step4 lbs/yd^3	Step5	Step6 lb/ yd^3	Step7 lb/ yd^3	Step8 lb/ yd^3
fc’ psi	9000							
Slump	2 in							
Agg %		0.68						
Wt of Agg			1891					
Water				300				
Air				2.0%				
w/c					0.36			
Cement						733		
Silica fume 6%						50		
Fly ash 6%						50		
Fresh concrete							3890	
Sand								866

4.4 CASTING OF SPECIMENS

4.4.1 PREPARATION OF MOULDS AND COMPACTION

Standard steel molds were used for the specimens. These were properly oiled before filling of concrete.

Every effort was made for controlled compaction to reduce segregation as much as possible.

4.4.2 CAPPING OF THE MOULDS

To achieve better result, it was necessary to give smooth top surface to the specimens. For this purpose methods available previously were:

a. Trowelling with steel '*Gurmala'*
b. Sulphur capping
c. Plaster of Paris capping

We used first method to give smooth surface to the specimen.

4.4.3 DETAILS OF SPECIMENS

Standard ASTM methods are followed during the entire process of mix design and testing of specimens. In order to achieve high strength we use silica fume and fly ash. The tests were conducted after 7 days, 14 days, 21 days and 28 days of curing. Various details about the specimens are given below:

Details about Specimens

Table 4.15

Day	Pure cement			Silica fumes 12%			Fly ash 12%			Silica fume 6%& fly ash 6%		
	Cylinders	Cubes	Prism	Cylinders	Cubes	Prism	Cylinders	Cubes	Prism	Cylinders	Cubes	Prism
7	2	2	2	2	2	2	2	2	2	2	2	2
14	2	2	2	2	2	2	2	2	2	2	2	2
21	2	2	2	2	2	2	2	2	2	2	2	2
28	2	2	2	2	2	2	2	2	2	2	2	2

4.4.4 DEMOULDING AND CURING OF SPECIMEN

All specimens were demoulded after 24 hours of casting and then were placed in water for next duration.

'Nowshehra' water was used for curing of the specimens.

Finally, the specimens were taken out of water after the calculated time period and were tested for various results as per the requirements.

4.5 TESTING MACHINE

Testing machine characteristics, mainly load capacity and stiffness can have a significant influence on measured strength results. Good test results and minimum variation have been obtained when testing high-strength concrete cylinders using a testing machine with a minimum lateral stiffness of 10^5 lb. /in and a longitudinal stiffness of at least 10^7 lb. /in. Testing machines that are laterally flexible can reduce the measured compressive strength of a specimen.

CHAPTER 5

TESTING OF SPECIMEN AND RESULTS

5.1 COMPRESSION TESTING

Results presented in this discussion are based on testing of 02 specimens for each mixes using different cementitious materials. In all the mixes for a particular strength and admixture the mix design was kept constant. Results of these samples are compared with each other.

5.1.1TEST RESULTSOF CONCRETE

Test results of the compressive strength of concrete are summarized. The maximum compressive strength to be achieved by the mix designs was 9,000 psi. The details of various test results are shown in specified tables and graphs.

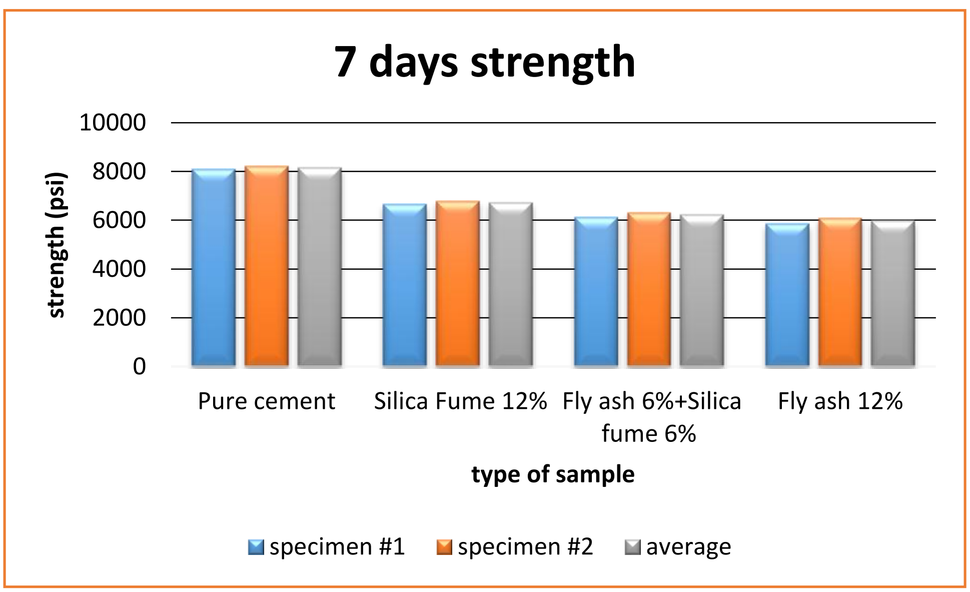
07 DAYS COMPRESSIVE STRENGTH

CUBES

7 DAYS strength

Table 5.1

SAMPLE	PURE CEMENT		SILICA FUME 12%		FLY ASH 12%		SILICA FUME 6% + FLY ASH 6%	
	kN	psi	kN	Psi	kN	psi	kN	psi
1	1300	8089	1070	6658	940	5849	985	6129
2	1320	8213	1090	6782	980	6098	1015	6316
Average	1310	8151	1080	6720	960	5973	1000	6222

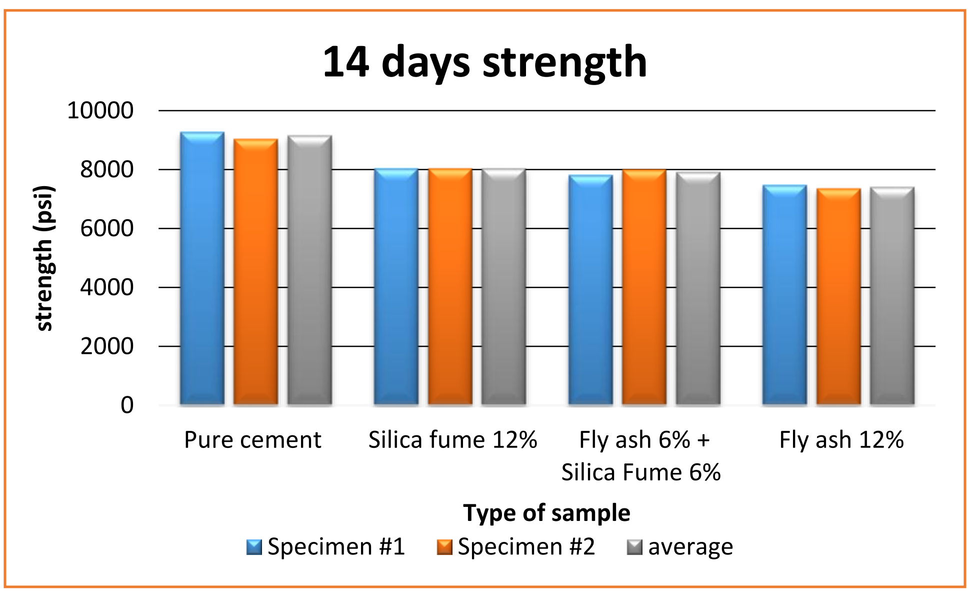


Graph 5.1

14 DAYS strength

Table 5.2

SAMPLE	PURE CEMENT		SILICA FUME 12%		FLY ASH 12%		SILICA FUME 6% + FLY ASH 6%	
	kN	psi	kN	Psi	kN	psi	kN	Psi
1	1490	9271	1290	8027	1200	7467	1255	7809
2	1450	9022	1290	8027	1180	7342	1285	7996
AVERAGE	1470	9147	1290	8027	1190	7404	1270	7902

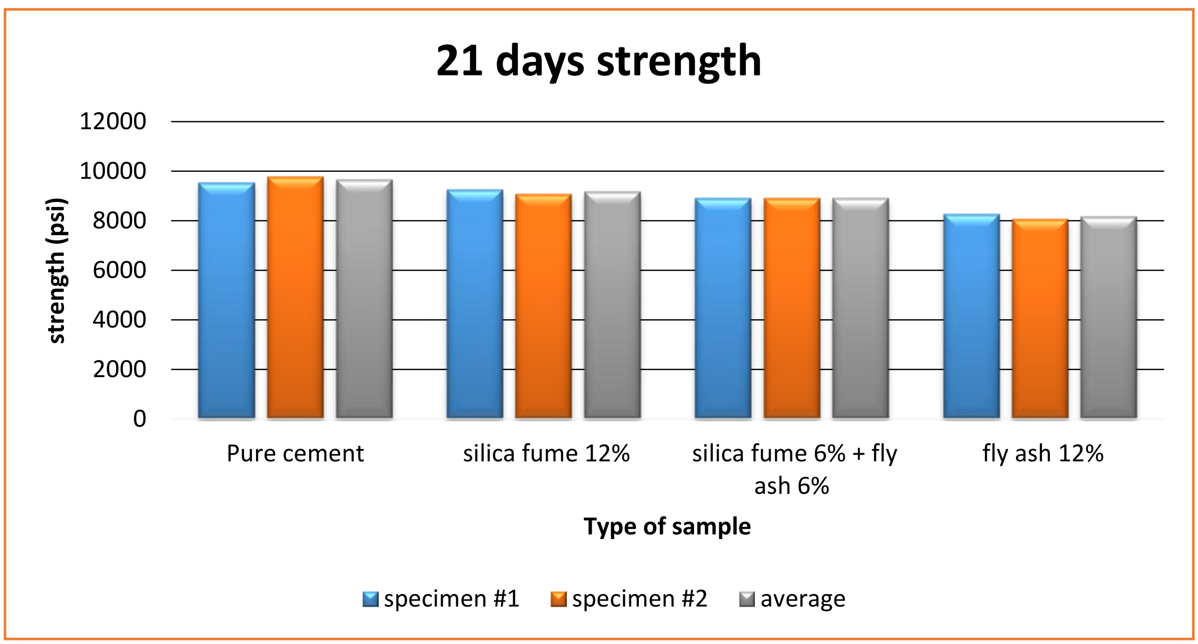


Graph 5.2

21 DAYS strength

Table 5.3

SAMPLE	PURE CEMENT		SILICA FUME 12%		FLY ASH 12%		SILICA FUME 6% + FLY ASH 6%	
	kN	psi	kN	Psi	kN	psi	kN	Psi
1	1530	9520	1485	9240	1325	8244	1430	8898
2	1570	9769	1455	9053	1295	8058	1430	8898
AVERAGE	1550	9644	1470	9147	1310	8151	1430	8898

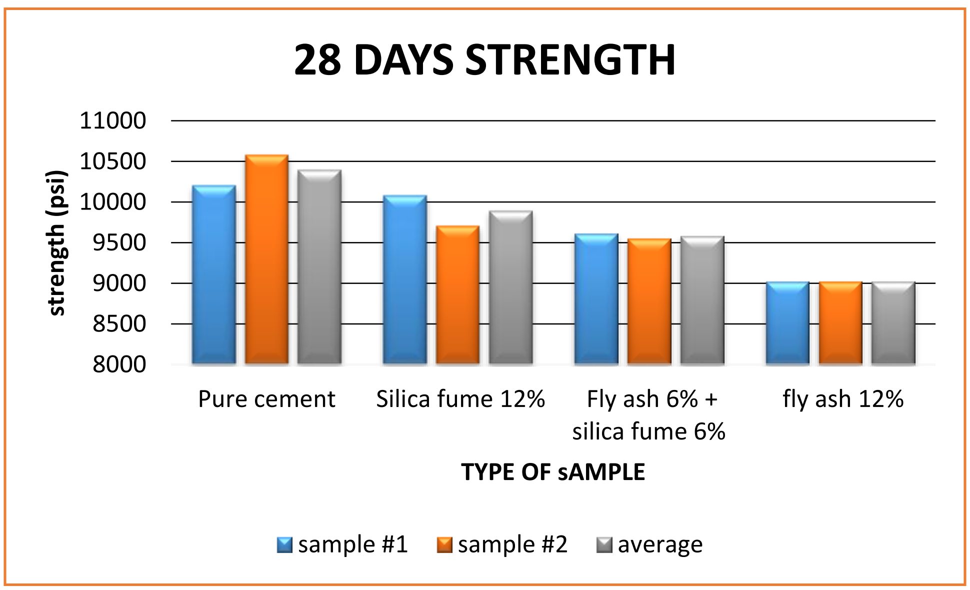


Graph 5.3

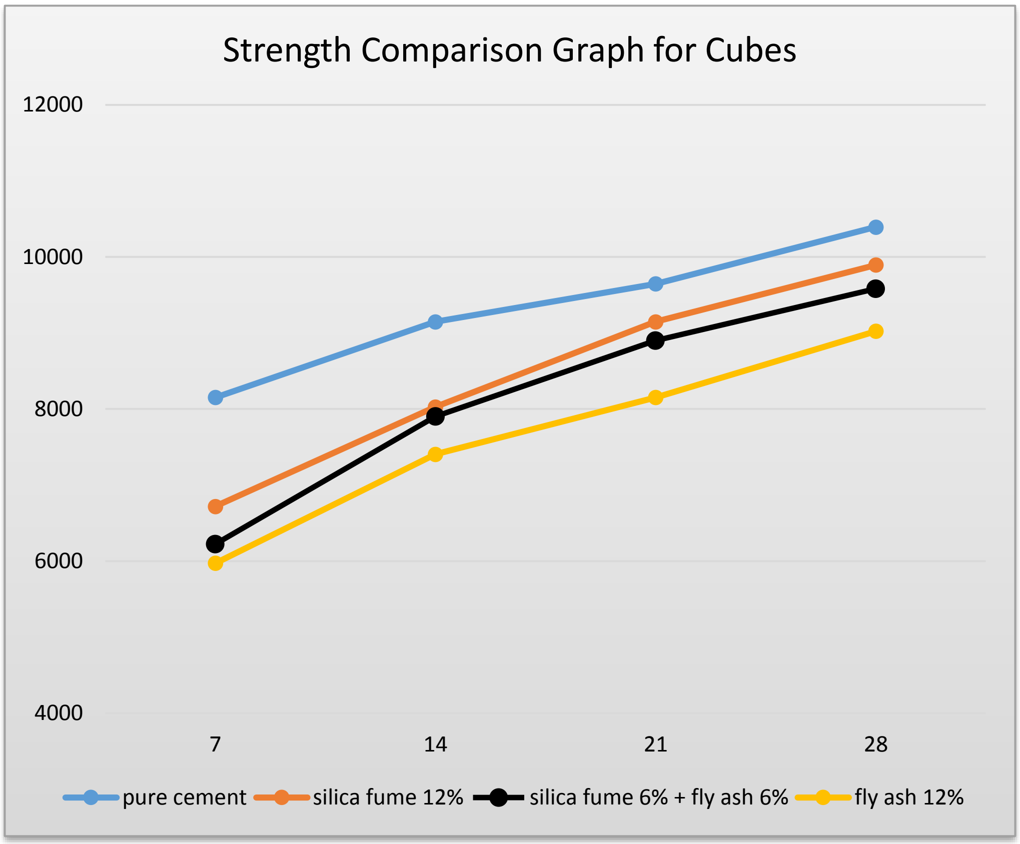
28 DAYS strength

Table 5.4

SAMPLE	PURE CEMENT		SILICA FUME 12%		FLY ASH 12%		SILICA FUME 6% + FLY ASH 6%	
	kN	psi	kN	Psi	kN	psi	kN	psi
1	1640	10204	1620	10080	1450	9022	1545	9613
2	1700	10578	1560	9707	1450	9022	1535	9551
AVERAGE	1670	10391	1590	9893	1450	9022	1540	9582



Graph 5.4


Strength Comparison Graph for Cubes
12000
10000
8000
6000
4000
7
14
21
28
pure cement
silica fume 12%
silica fume 6% + fly ash 6%
fly ash 12%

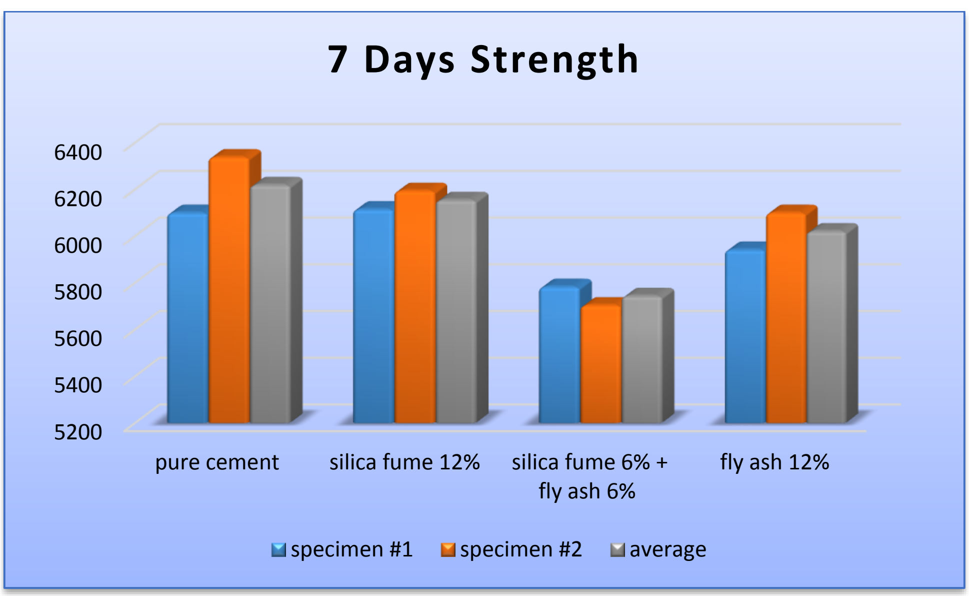
Graph 5.5

Cylinders

7 DAYS strength

Table 5.5

SAMPLE	PURE CEMENT		SILICA FUME 12%		FLY ASH 12%		SILICA FUME 6% + FLY ASH 6%	
	kN	psi	kN	psi	kN	psi	kN	Psi
1	770	6099	772	6114	730	5782	750	5941
2	800	6337	782	6193	720	5703	770	6099
AVERAGE	790	6218	777	6154	725	5743	760	6020

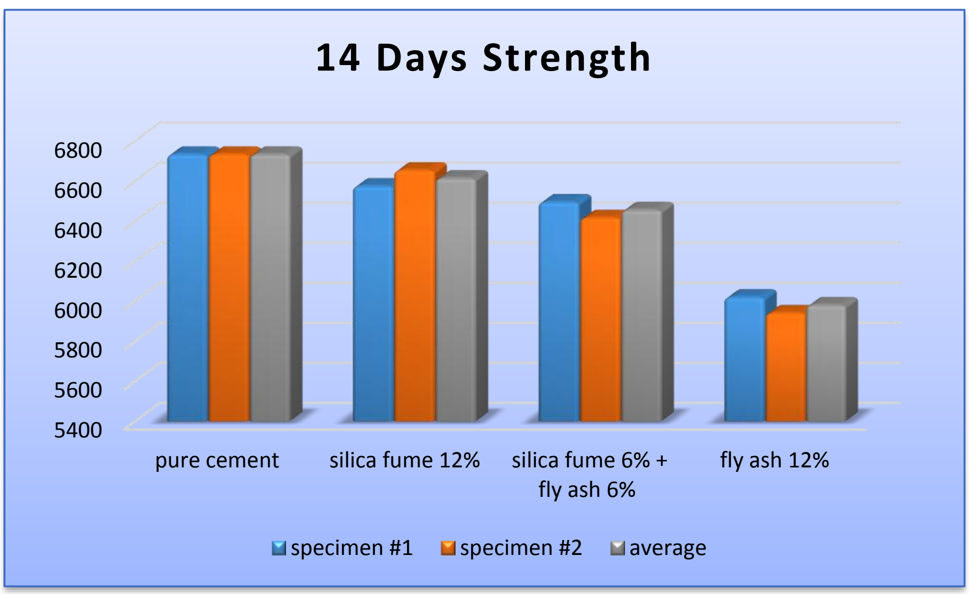


Graph 5.6

14 DAYS

Table 5.6

SAMPLE	PURE CEMENT		SILICA FUME 12%		FLY ASH 12%		SILICA FUME 6% + FLY ASH 6%	
	kN	psi	kN	psi	kN	psi	kN	Psi
1	850	6733	830	6574	760	6020	820	6495
2	850	6733	840	6653	750	5941	810	6416
AVERAGE	850	6733	835	6614	755	5980	815	6455

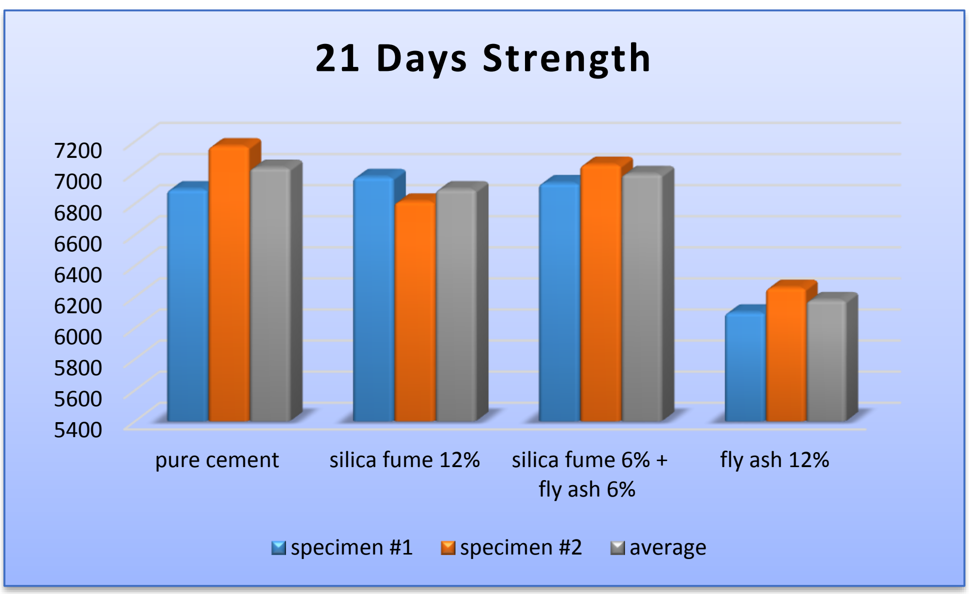


Graph 5.7

21 DAYS

Table 5.7

SAMPLE	PURE CEMENT		SILICA FUME 12%		FLY ASH 12%		SILICA FUME 6% + FLY ASH 6%	
	kN	psi	kN	Psi	kN	psi	kN	psi
1	870	6891	850	6733	770	6099	875	6931
2	905	7168	830	6574	790	6257	890	7050
AVERAGE	888	7030	840	6653	780	6178	883	6990

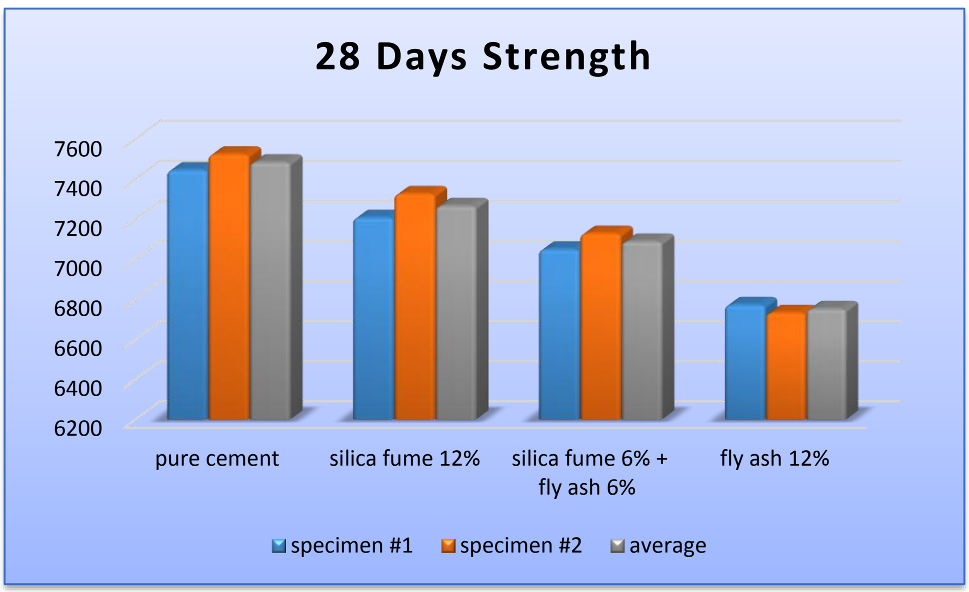


Graph 5.8

28 DAYS

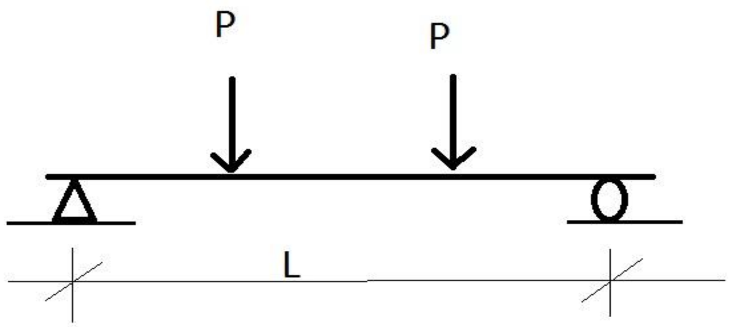
Table 5.8

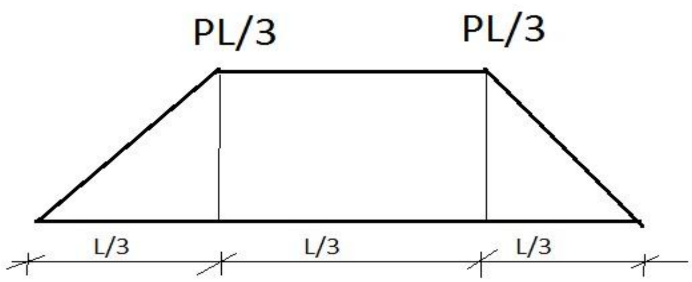
SAMPLE	PURE CEMENT		SILICA FUME 12%		FLY ASH 12%		SILICA FUME 6% + FLY ASH 6%	
	kN	psi	kN	Psi	kN	psi	kN	Psi
1	940	7446	910	7208	855	6772	890	7050
2	950	7525	925	7327	850	6733	900	7129
AVERAGE	945	7485	918	7267	853	6752	895	7089



Graph 5.9

Prisms





BRNDING MOMENT DIAGRAM

MAXIMUM MOMENT, M = PL/3

FLEXURAL STRENGTH, f_{CT} = MY/I -------------------------- eq(i)

y = d/2 = 4/2 = 2

I = bd^3 / 12 = 4 x 4^3 / 12=64/3

M = P'L / 3= P' x 14 /3 = 14P' / 3

P' = P/2 (as it is 3^{rd} point loading)

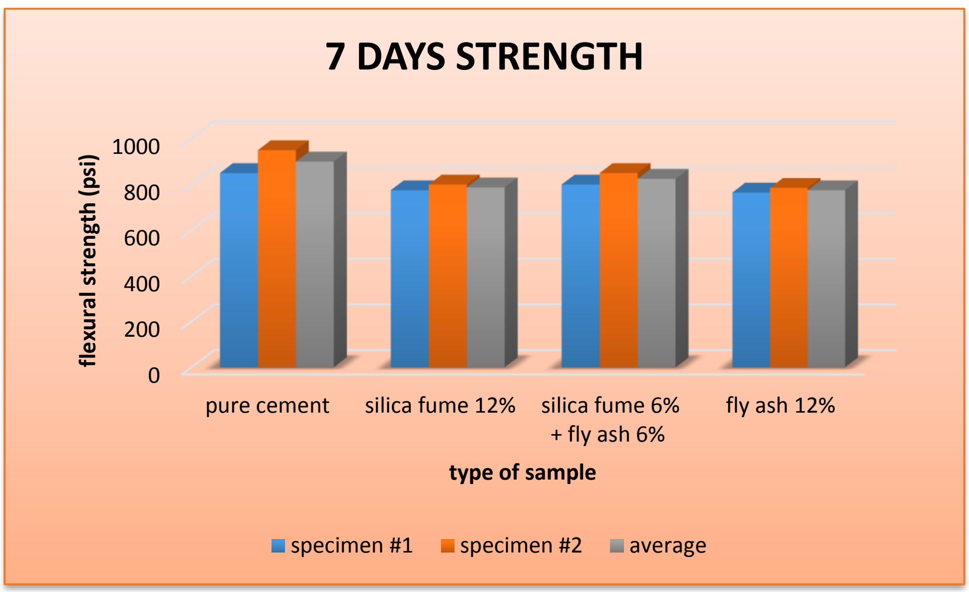
Putting values in eq (i)

f_{CT} = (7P / 3) x 2 / (64 /3) = 7P / 32

7 DAYS strength

Table 5.9

SAMPLE	PURE CEMENT		SILICA FUME 12%		FLY ASH 12%		SILICA FUME 6% + FLY ASH 6%	
	kN	psi	kN	Psi	kN	psi	kN	Psi
1	17	849	15.5	774	15.3	764	16	779
2	19	949	16	799	15.7	784	17	849
AVERAGE	18	899	15.75	787	15.5	774	16.5	824

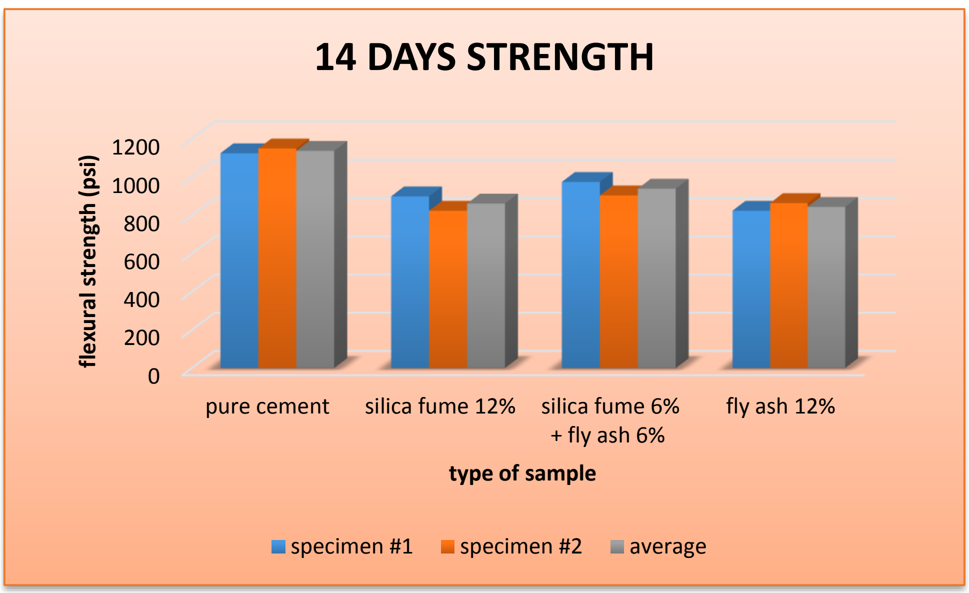


Graph 5.10

14 DAYS strength

Table 5.10

SAMPLE	PURE CEMENT		SILICA FUME 12%		FLY ASH 12%		SILICA FUME 6% + FLY ASH 6%	
	kN	psi	kN	psi	kN	psi	kN	Psi
1	22.5	1124	18	899	16.5	824	19.5	974
2	23	1149	16.5	824	17.3	864	18.1	904
AVERAGE	22.75	1136	17.25	862	16.9	844	18.8	939

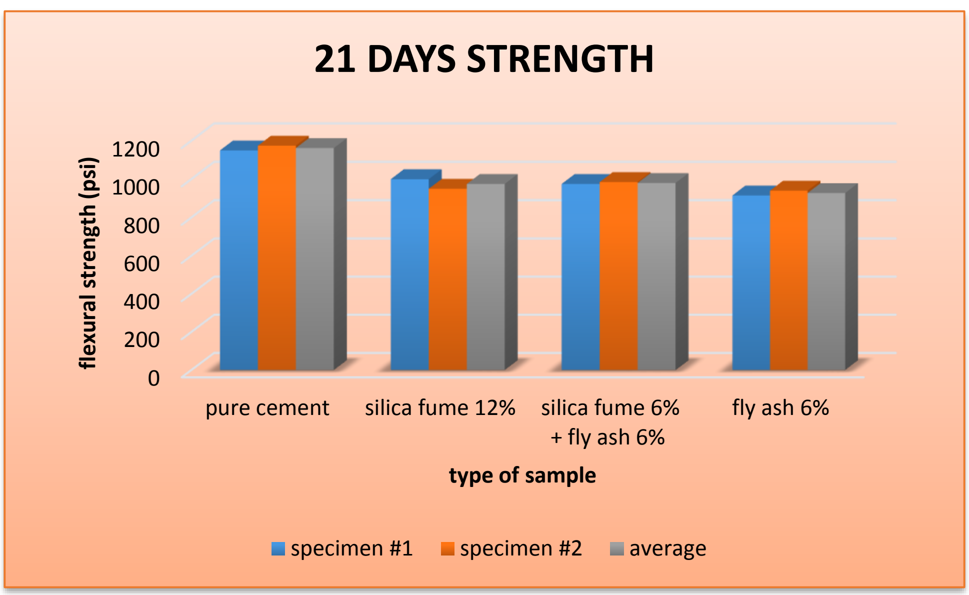


Graph 5.11

21 DAYS strength

Table 5.11

SAMPLE	PURE CEMENT		SILICA FUME 12%		FLY ASH 12%		SILICA FUME 6% + FLY ASH 6%	
	KN	psi	KN	psi	KN	psi	KN	psi
1	23	1149	20	999	18.3	914	19.5	974
2	23.5	1174	19	949	18.8	939	19.7	984
AVERAGE	23.25	1161	19.5	974	18.55	926	19.6	979

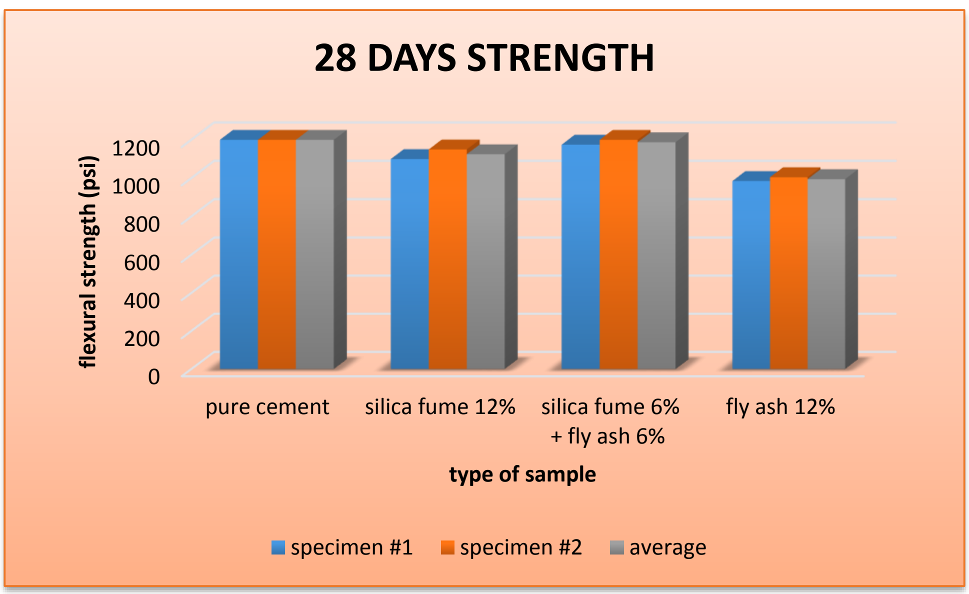


Graph 5.12

28 DAYS strength

Table 5.12

SAMPLE	PURE CEMENT		SILICA FUME 12%		FLY ASH 12%		SILICA FUME 6% + FLY ASH 6%	
	kN	psi	kN	psi	kN	psi	kN	Psi
1	24	1199	22	1099	19.7	984	23.5	1174
2	24	1199	23	1149	20.1	1004	24	1199
AVERAGE	24	1199	22.5	1124	19.9	994	23.75	1186

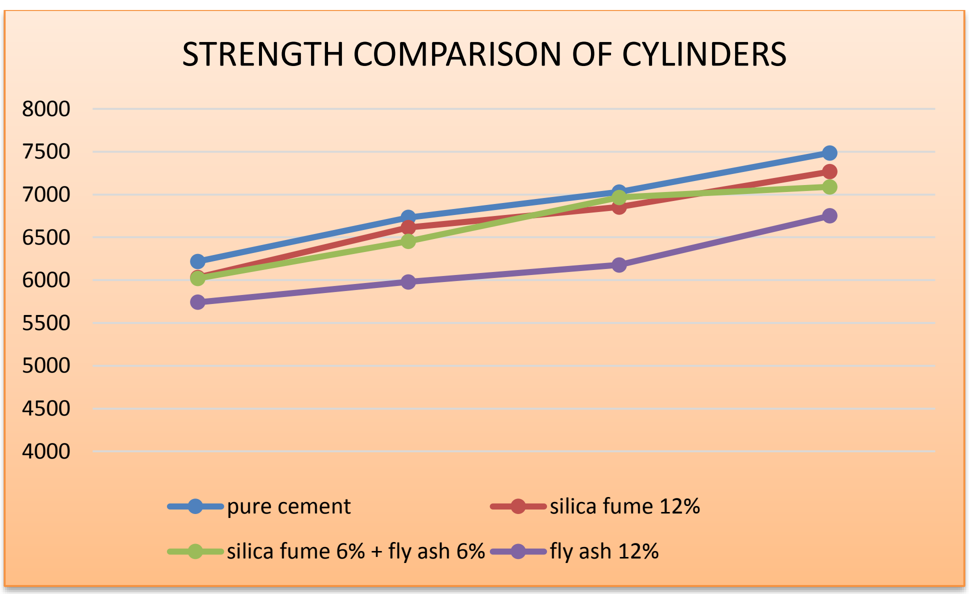


Graph 5.13

5.2 EFFECT OF AGE ON COMPRESSIVE STRENGTH OFCONCRETE

In concrete design the strength of concrete is traditionally reffered at 28-day age,and some other properties of concrete are often referred to the 28-day strength. It is arguable that a shorter period than 28-days could be used for the characterization of strength,but the age of 28 days seems to have acquired an immutable position. If, for some reason, the 28-day strength is to be estimated from the strength determined at an earlier age, say 07 days or 03 days, then the relation between the 28-day and 07-day or 03-day strengths has to established experimentally for the given mix.

For high strength concrete 07-day strength is usually about 70 % of the 28-day strength, 14 days strength is about 85 % and 21 days strength is about 90 to 95 % of 28 days strength. Following graph shows the strength development of various mixes with age . Cylinders strengths are used in this graph.



Graph 5.14

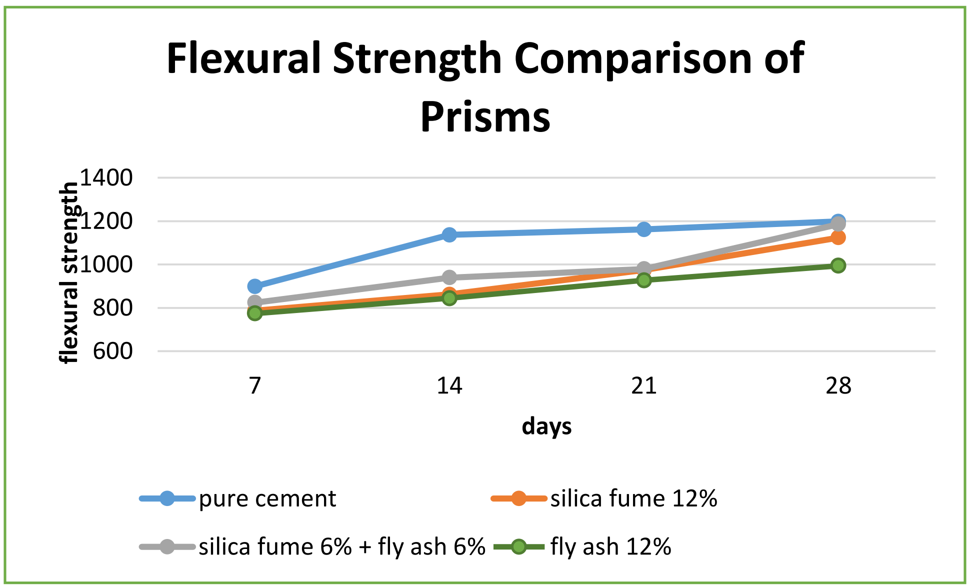
5.3 EFFECT OF AGE ON FLEXURAL STRENGTH OFCONCRETE

ACI 318 – 08 Section 9.5.2.3 gives the following equation to predict modulus of ruture from comprresive strength**.**

$$\mathbf{F_r = 7.5 \ x \ \lambda \ x \ (f'c)^{1/2}}$$

But the flexural strength of High Strength Concrete is much more than that predicted by this formula.

Following graph shows the flexural strength development with age. Prisms strengths are used to plot this graph.



Graph 5.15

CHAPTER 6

CONCLUSIONS & RECOMMENDATIONS

6.1 CONCLUSIONS

The demand of high strength concrete is likely to increase because of its cost effectiveness, durability and performance. It is increasingly reducing the demand of steel in construction of high rise buildings and huge structures In Pakistan this technology is new but in the days to come due to the obvious advantages is likely to be an attractive for tall and important structures.

The increased durability and strength are the most important factors which add credibility for use in today's expanding world. After detailed investigations, the conclusions drawn are summarized below: -

a. With the selected percentage composition, no significant effect of silica fume or fly ash, pure cement give higher values.

b. High strength concrete gives higher modulus of rupture.

c. High strength concrete requires a more amount of water content for a given workability than normal concrete.

d. Addition of silica fume causes considerable slump loss, so more quantity of plasticizer is required.

e. High strength concrete requires a more amount of water content for a given workability than normal concrete. Additional water demand of 5 lb for every 100 lb of cement above 500 lb cement appears valid.

f. Mixes containing fly ash and silica fume show low early strength but later, a jump in strength is observed as compared to mixes made with cement only.
g. Mixes containing fly ash as replacement of cement show some erratic behavior of strength development with age.
h. Addition of silica fume causes considerable slump loss, so more quantity of plasticizer is required.
i. Mixes containing silica fume show reduced bleeding.
j. Addition of Fly Ash leads to increase in the slump of concrete.

6.2 COMMENTS

Compressive strength of 9,000 psi was not obtained due to the following reasons:

1. Aggregate was weak although it was among the best aggregates available in Pakistan.
2. The super plasticizer used had dual action i.e high range water reducer and accelerator. Whenever an accelerator is used it gives elevated early strength but reduced 28 day strength.
3. Water leaked from the curing tank available in concrete lab. So, proper curing was not achieved during those specific days of water leakage.
4. Due to the old machinery there might be reading errors.

.

6.3 RECOMMENDATIONS

Use of High-strength Concrete in developed countries is quite common but unfortunately its use in Pakistan is very rare. Since Pakistan's population is expected to double over the next forty years, the demand for the improved building materials such as high strength concrete is likely to be phenomenal; this justifies large investments in research in high strength concrete. Keeping in view the high population growth rate, urbanization, congestion and paucity of space in major cities of Pakistan, High Strength Concrete due to its obvious advantages seems to have a great scope. Therefore, it is need of the hour that our Engineers and construction industry should carry out research work on this concrete.

Proposed areas of further research for scholars can be:-

a. Replace 15 or more % of cement with pozzolona.

b. Behavior of High Strength Concrete in hot climate.

c. Economic evaluation of high strength concrete developed on different w/c ratios

d. To study the effects of aggregates from different origins on the strength of normal & HSC.

REFERENCES

1. Kaar, P.H. hanson, N.W. and Capell, H.T. (1977) Stress-strain characteristics of high strength concrete. Research and Development Bulletin.
2. Nilson. A.H. and Slate, F.O. (1979) Structural design prosperities of every high strength concrete. Second progress Report, NFS Grant ENG 7805124, School of Civil and Environmental Engineering, Cornell University, Ithaca, New York.
3. Committee 211.4R Guide for selecting Proportions for High-Strength Concrete with Portland Cement and Fly Ash, ACI Materials Journal, November-December, 1993.
4. Walker, S. and Bloem, D.L. (1960) Effects of aggregate size on properties of concrete. ACI Journal, 32, 3, September 283-98.
5. Malhotra, V.M. (ed.) (1983) Fly ash, silica fume, slag and other mineral by-products in concrete, SP 79, vol II, American Concrete Institute.
6. Ronne, M. (1987) Effect of condensed silica fume and fly ash on compressive strength development of concrete. American Concrete Institute, SP-114-8, 175-89.
7. Neville, A.M. (1981) Properties of concrete, Third edition. Pitman Publishing Ltd., London.
8. Committee 318 (2008) Building code requirements for reinforced concrete. American Concrete Institute.
9. Committee 363 (1984) State-of-the-art report on high strength concrete. ACI Journal, 81, 4, July-Aug, 364-411.
10. Committee 363 (1984) State-of-the-art report on high strength concrete. ACI Materials Journal, November-December, 559-61.
11. Aitcin, P.C. (1983) Condensed silica fume. University of Sherbrooke, Sherbrooke, Quebec.
12. Philleo, R.E. (1955) Comparison of results of three methods for determining Young's Modulus of elasticity of concrete. ACI Journal, 51, Jan 461-9.
13. ACI Committee 1987, Erdogan 1997
14. Goldman & Bentur 1993; Aiqin et al 2003
15. www.aboutcivil.com