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Thesis entitled

ANALYZING THE STRENGTH PROPERTIES OF HIGH PERFORMANCE CONCRETE

Submitted By

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Has been accepted towards the partial fulfillment
of the requirements
for
Master of Science in Civil Engineering, Specializing in Structural Engineering

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ANALYSING THE STRENGTH PROPERTIES OF HIGH PERFORMANCE CONCRETE

By

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A Thesis

of

Master of Science

Submitted to the

National Institute of Transportation, Risalpur

of

National University of Sciences and Technology

Rawalpindi, Pakistan

In partial fulfillment of the requirements

for the degree of

Master of Science

(April, 2003)

DEDICATED TO MY LOVING FAMILY

ACKNOWLEDGEMENTS

I bow my head praising Allah Almighty and offer my salat o salam to his beloved Prophet Muhammad (peace be upon him), for all the blessings He showered upon me by providing an opportunity to seek and learn the “ Naffay Knowledge”.

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 me to carry out this research work.

It is with the great pleasure and profoundest feelings of obligations that, I thank Dr Sana Ullah Balouch, National Institute of Transportation, Risalpur, under whose able guidance, this work has been done. His contributions included personal and professional advice. I also feel deeply indebted to Mr Sardar Khan, Lecturer at Military College of Engineering, Risalpur for taking personal interest in streamlining the scope of research work and paying special attention to my problems during the thesis work by extending his help very generously.

I am grateful to Lieutenant Colonel (R) Muhammad Iqbal and Dr Farhat Javed for their valuable advice and encouragement. I also wish to place on record my humble thanks to the laboratory and technical staff, without the skilled assistance of whom it would not have been possible to carry out most of the experiments.

At the end my gratitude and abundant thanks are due to my wife for showing patience and continued encouragement.

ABSTRACT

Concrete being the most widely used material in civil engineering for infrastructural development. The improvement and further development of this material has always been on tips of civil engineers in their research projects. It has now been recognized that concrete with many of its newer combinations and additives in the form of cement based composites has improved its properties.

High performance concrete represents a recent development in the advancement of concrete materials technology. Now, it is established that high performance concrete is of high quality and lower cost. High performance concrete is not a commodity but a range of products, each especially designed to satisfy in the most effective way the performance requirements for the intended application. High performance concrete mixtures contain, higher cement content, lower w/c ratios, strong aggregates, cementicious materials like silica fume and high range water reducers. Such mixtures, when properly mixed, placed, consolidated and cured yield very high strength and excellent performance.

For this research the effects of different replacement levels of cement by silica fume (5%, 10% & 15%), incorporating the coarse aggregates from two major sources Sargodha and Margala were studied. All the mixtures were prepared with constant w/c ratio 0.25. Strength properties including compressive, tensile, flexure and modulus of elasticity were analysed. Optimum replacement level of cement by silica fume that satisfied the economical performance in terms of all the strength properties is identified. Potential applications in high-rise buildings, long span bridges and off-shore structures are suggested. Finally the research is concluded with further future prospects.

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NOTATIONS AND ABBREVATIONS

ACI = American Concrete Institute

ASTM = American Society of Testing Materials

HPC = High Performance Concrete

SF = Silica Fume

Approx = Approximately

Cu = Co-efficient of uniformity

Cc = Co-efficient of conformity

Ft = Feet

Kg = Kilo gram

Lbs = Pounds

Max = Maximum

Min = Minimum

mm = Millimeter

Psi = Pounds per square inch

Ref = Reference

Sq = Square

s.no = Serial number

UN = United Nations

vs = verses

w/c = water / cement ratio

C/F = Coarse / Fine Ratio

CHAPTER – 1

INTRODUCTION

1.1 General

Concrete as a construction material has undergone a continuous evolutionary process. Strength of 2000psi was considered adequate at the turn of 20th century. Today concrete having strength upto 20,000 psi are being used. The rapid developments in concrete research over the past 30years has opened new and proficient utilization of components available in nature including industrial “wastes” such as silica fume. The Silica Fume is an industrial “waste” of few decades ago but now is an integral element of new 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.

High performance concrete is the latest development in concrete technology and is a term used to describe concrete with special properties not attributed to normal concrete. High Performance Concrete was first known to be concrete with high strengths for structural purpose. However, advancement in concrete technology has generated a new definition for High Performance Concrete. High Performance means that the concrete has one or more of the following properties: low shrinkage, low permeability, a high modulus of elasticity and high strength. As a consequence High Performance Concrete is referred as concrete with better durability or higher strength compared to normal and moderate strength concrete.

High Performance Concrete is a very economical material for carrying vertical loads in high-rise structures, bridges, rehabilitation of existing and structures under severe exposure conditions. High performance concrete also, provides enhanced mechanical properties in precast structural elements including higher tensile and compressive strengths as well as high modulus of elasticity (stiffness). In high performance concrete, materials and admixtures are carefully selected and proportioned ("optimized") to develop high early strengths, high ultimate strengths, and durability beyond conventional concrete.

1.2 The Need for High Performance Concrete

Normal strength concrete is heavy and lacks the required performance characteristics in some large structures, such as high-rise buildings, bridges, and structures under severe exposure conditions. By increasing concrete strengths and performance, the required thickness of concrete members and the cost of concrete structures can both be reduced.

1.3 Prospects of High Performance Concrete in Pakistan

Use of High Performance Concrete in developed countries is quite common but unfortunately its use in Pakistan is very rare. High Performance Concrete has somewhat higher initial cost per unit volume than conventional concrete, however, its use is latterly to be justified by saving in over all cost and by the obvious advantages which are as below: -

a. The early stripping of formwork.
b. The enhance workability.
c. The enhanced durability and service life.
d. The enhanced mechanical properties and reduced size of structural elements.
e. Ease of placement and compaction without segregation.
f. High toughness.
g. Volume stability and better control of deformations.
h. Increased building height.
j. The reduced construction cost.
k. Longer spans and wider members spacing.

l. 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.

Keeping in view the high population growth rate, urbanization, congestion and paucity of space in major cities of Pakistan, High Performance Concrete due to its obvious advantages seems to have a great scope. Therefore, it is need of the hour that our Engineer Community and construction industry should carry out research work on the High Performance Concrete as the future belongs to High Performance Concrete.

1.4 Objectives

The research work is focused on the study of the high performance concrete by replacing different levels of silica fume and using super plasticizer. The main objectives of the research work are:

a. To determine the "optimum" replacement level of silica fume to produce an economical high performance concrete.

b. To analyses the strength properties of high performance concrete.

1.5 Research Methodology

The research strategy that was followed in order to achieve the main objectives is described as under:-

1.5.1. Constituent Materials

For the present investigations, materials used are given in table 1.1 below:-

Table 1.1 Constituent Materials

S/No	Item	Description
1	Silica Fume	Procured from SIKA&MBT chemicals.
2	High Range Water Reducing Admixtures	Procured from SIKA Construction Chemicals.
3	Cement	Ordinary Portland cement from CHERAT cement factory.
4	Coarse Aggregate	Crushed stone from Sargodha and Margala
5	Sand	Lawrncepur Sand
6	Water	Potable water from Nowshera was used.

1.5.2 Development of High Performance Concrete Mix Proportions

After procurement of materials, no of trail batches based on different levels of replacement of cement with silica fume and varying the basic mix proportions were prepared and strength properties were analyzed for optimum level of replacement of cement with silica fume. Detail of the laboratory trial mixtures is given in table 1.2 below:-

Table 1.2 Detail of the Trial Mixtures

Mix #	COMPOSITION	BASIC MIX (Cement Only) Ibs/yd^3	C + SF (5%) Ibs/yd^3	C + SF (10%) Ibs/yd^3	C + SF (15%) Ibs/yd^3	REMARKS
Mix – I	Cement	950	902	854	806	w/c = 0.25 C/F = 1.63
	Silica Fume	-	48	96	144	
	Sand (Dry)	1100	1100	1100	1100	
	Stone (Dry)	1800	1800	1800	1800	
	Water	238	238	238	238	
Mix – II	Cement	1000	950	900	850	w/c = 0.25 C/F = 1.71
	Silica Fume	-	50	100	150	
	Sand (Dry)	1050	1050	1050	1050	
	Stone (Dry)	1800	1800	1800	1800	
	Water	250	250	250	250	
Mix –III	Cement	1100	1045	950	935	w/c = 0.25 C/F = 1.8
	Silica Fume	-	55	110	165	
	Sand (Dry)	1000	1000	1000	1000	
	Stone (Dry)	1850	1850	1850	1850	
	Water	275	275	275	275	

- High Range Water Reducer was used as 1.5%(% of cement and Silica Fume)
- C+ SF = Cement + Silica Fume
- C/F = Coarse to Fine Aggregate ratio

1.5.3 Testing.

Testing was carried out in two phases: -

Phase 1. Testing of the constituent materials.

Phase 2. Strength Properties of the concrete such as compressive strength, tensile strength, modulus of rupture and modulus of elasticity were investigated.

CHAPTER – 2

LITERATURE REVIEW

2.1 Necessity for High Performance Concrete

For many years, high-strength, high-performance concrete has been used in the columns of high-rise buildings. However, in recent years, there has been increased in use of high-performance concrete in bridges where both strength and durability are important considerations. The primary reasons for selecting high performance concrete is to produce more an economical product, provide a feasible technical solution, or a combination of both.

At the present time, a cubic yard of high performance concrete costs more a cubic yard of conventional concrete. High performance concrete requires additional quantities of materials such as cement, silica fume, high range water reducers and retarders to ensure that the concrete meets the specified performance. 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. On the other hand, high performance concrete should not be specified if there are no technical or economical advantages to be gained from its use. Why to use high performance concrete in high-rise buildings, bridges and offshore structure are explained in the succeeding paragraphs.

2.1.1 Buildings

The economic advantages of using high-strength, high-performance concrete in the columns of high-rise buildings have been known for many years. 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 les 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 has been specified for the concrete in several high rise buildings. The most notable building is Two Union Square in Scattle where a modulus of elasticity of 7.2 million psi (50 GPa) was required in addition to a compressive strength of 14000 psi (97 Mpa). To achieve this modulus of elasticity, a compressive strength of 19000 psi (131 MPa) was required. A higher modulus of elasticity provides a stiffer structure which has les lateral deflection under wind loads.

2.1.2 Bridges

In 1993, the Federal Highway Administration (FHWA) initiated a national program to implement the greater use of HPC 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 HPC 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.

High performance concrete was used on a bridge on S.R 516 near Auburn, Wash. The use of concrete with a specified strength of 10000 psi (69 Mpa) for the pre-stressed concrete girders resulted in five lines of girders compared to seven lines that would have been required with normal strength concrete. In addition to strength, the concrete was required to have a rapid chloride permeability not exceeding 2000 coulombs and a freeze thaw resistance greater than 80 percent.

In Colorado, an HPC 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 HPC Bridge used 10000 psi (69 Mpa) concrete and consisted of two spans in place of the original four spans. The use of HPC, in combination with adjacent box beams, met the requirements for longer spans while maintaining a shallow superstructure depth.

High performance 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. At the present time, most states are specifying a limit on chloride permeability for their HPC decks.

The goal is to specify quantifiable performance to match the intended application. However, electing durability performance requirements can be difficult, and specifications are usually a combination of prescriptive and performance requirements.

In Virginia, moist curing of HPC bridge decks is required for a minimum of seven days and until 70 percent of the specified 28 days strength is obtained. Protection by fogging to prevent rapid drying of the concrete burlap and plastic sheeting is required. After moist curing a curing compound is applied to the deck surface. Most states with HPC Bridge require at least seven days of curing for the concrete.

Unlike high performance concrete in building, the use of high performance concrete in bridges is more difficult to justify based on initial costs only. The economic advantage of HPC varies depending of the premium cost for the HPC product. In many of the HPC bridges built to date, the premium cost for the HPC has not been entirely affected by saving in materials. However, as more contractors and producers develop op experience with HPC, it is anticipated that the premium will decrease and initial costs will compare more closely with costs for conventional concrete bridges.

With bridges, there are additional costs associated with maintenance and repair. The use of HPC 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.

2.1.3 Offshore Structures

Concrete with compressive strength in excess of 6000 psi (41 Mpa) have been used in offshore structures since the 1970s. 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 Aretic. This exploratory drilling structure contains about 12000 cu yd (9200 cu m) of high strength lightweight concrete with unit weights of about 1121 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 cu m) of high strength normal weight concrete with unit weights of about 145 lb/ft^3 (2.32 Mg/m^3) and 56 days compressive strengths of about 10000 psi (69 Mpa).

2.2 Materials for High Performance Concrete

High Performance Concrete is prepared through a careful selection of each ingredient. The performance and quality of each ingredient become 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 performance 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 performance 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 performance concrete, any material incompatibilities will highly detrimental to the finished product. Thus, the culmination of any mix design process must be the extensive testing of trial mixes.

2.2.1 Selection of Cement

The first choice to be made when making high performance concrete is definitely that of the cement, even when one or two supplementary cementitious materials will be used, because the performance of the cement in terms of rheology and strength become crucial issue as the targeted compressive strength increases. Different brands of given ASTM type of cement do not perform in the same way when making high performance concrete. Some perform very well in terms of final strength, but very poorly in terms of rheological 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 reheology; their slump loss within the first 1 or 2 hours is minimal. However, they perform very poorly in terms of compressive strength. High performance concretes have been produced successfully using cements meeting the ASTM standard specification C150 for Types I, II and III Portland cements. Unfortunately, ASTM C150 is very imprecise in its chemical and physical requirements, and so cements which meet these, rather loose specifications, can vary quite widely in their fineness and chemical composition. When choosing Portland cements for use in high performance concrete, it is necessary to look carefully at the cement fineness and chemistry.

2.2.1.1 Fineness

Increasing the fineness of the Portland cement will, on the one hand increase the early strength of the concrete, since the higher surface area in contact with water will lead to a more rapid hydration. On the other hand too high a fineness may lead to rheological problems, as the greater amount reactions at early ages, in particular the formation of ettringite, will lead to higher loss of slump loss. Most cements now used to produce high performance concrete have Blaine fineness that are in the range of 1467 to 1957 ft^2/Ib, though when type III (high early strength) cements are used, the fineness are in the range of 2201 ft^2/Ib.

2.2.1.2 Chemical Composition of the Cement

The Perenchio has shown that the 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 performance 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.

2.2.2 The Search for Strong Aggregates

The selection of particularly strong aggregates is not necessary when producing usual concrete. Generally, it is only necessary to check that standard performance requirements for aggregates are met. On the other hand, in high performance concrete , the hydrated cement paste and the transition zone can be made so strong that, if the aggregates, particularly the coarse ones, are not strong enough, these can become the weakest link within the concrete. The aggregates used to make high performance 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: they must be used as they are. Using crushed aggregates to make high performance 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.

2.2.2.1 Coarse Aggregate

In high performance concrete the coarse aggregate particles themselves must be strong. The shape and surface texture affect the total mixing water requirements. A careful consideration should be given to the shape, surface texture, and mineralogy of the coarse aggregate. These characteristics, 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 and are enlisted in Table 2.2.

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 be differences between the elastic module 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. Metha and Aiticin have recommended that equidimentional particles from crushing of either dense limestone or igneous rocks, of plutonic type (viz. Granite, senite, diorite, gabbro, diabase are generally satisfactory coarse aggregates.

2.2.2.2 Fine Aggregates

In conventional concrete fine aggregate has a primary function in providing workability. Since high performance concrete contains an unusual high amount of cement and pozzolan, the sand that provides good finishing characteristics in regular concrete is not as necessary. Sands with a fineness modulus (FM) around 2.5 produced concrete with very “sticky” characteristics, which resulted in loss of workability and higher water demands. Sands with a FM around 3.0, which are considered coarse under normal conditions, provided 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 Performance Concrete. The optimum gradation of fine aggregate for high strength is determined more by its effect on water than on physical packing. With rich concrete mixtures it is not necessary to use fine sand; in fact, coarse sands of having FM around 3 are preferred in order to keep the water requirement low, and to achieve better workability and compressive strength. As per Blick, Ronald L. sand with a FM below 2.5 gave the concrete a sticky consistency, making it difficult to compact compared to conventional concrete. High Performance Concrete typically contain such high content of fine cementitious materials that the grading of the aggregate used is relatively unimportant. 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.

2.2.3 Use of Silica Fume in High Performance Concrete

The silica fume also called micro silica, is used in concrete as a mineral admixture, especially in the production of high performance concrete. Silica fume is obtained as a byproduct, in electric arc furnaces used for metallic silicon or ferrosilicon alloys. The gaseous SIO_2 is oxidized and subject to high rate of cooling, which results in the condensation of very fine amorphous silica, with high pozzolanicity. It is mainly composed of amorphous SIO_2 (90-95%) along with other minority components (Fe2O3, Cao, mgo, etc) that depend on the type of the alloy produced in the furnace.

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.

2.2.3.2 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 progress and with better knowledge about silica fume concrete, also because the increased price, silica fume is now often used as an effective additive to produce a better quality concrete. High performance 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.

2.2.3.1 Chemical and Physical Composition of Silica Fume

Chemical composition of silica fume varies depending on the nature of the product from the manufacture process of which the silica fume is collected. The main constituent material in silica fume is silica (SIO2), the content of which is normally over 90%. The chemical analysis, physical properties of a commercially available silica fume as well as comparison of chemical and physical characteristics of silica fume, fly ash and cement are enlisted in Tables 2.3, 2.4 & 2.5.

Table2.1 Chemical composition of SF

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

Table 2.2 Physical Properties of Silica Fume

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

Table 2.3 Comparison of Chemical & Physical Characteristics – SF, Fly Ash and Cement

Description	Silica Fume	Fly Ash	Cement
SIO_2 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	-

2.2.3.3 Mechanism of Action

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):

$SiO2 + Ca\ (OH)2 + H2O \quad = \quad CaO.SiO2.H2O$

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).

Regarding the influence on the hydration processes, several authors, report an acceleration of the hydration of the hydration silicates of the cement in the presence of the silica fume. The fine silica fume particles appear to act as nucleation points, leading to a finer porosity, as well as denser and more homogeneous matrix.

The microstructure of the hardened cement paste is significantly modified by the incorporation of the silica fume, producing affine 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.

2.2.3.4 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 of Fresh Concrete** 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 of Fresh Concrete.** Concrete in cooperating more than 10% silica fume become strictly; 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 rheologic 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

2.2.3.5 The Influence of Silica Fume on the Properties of Hardened Concrete

The particulars advantage of using silica fume as a very fine and reactive pozzolan for use in high performance concrete was recognized. By using silica fume it has been shown that it is possible to make workable concrete with a compressive strength in the 100 – 150 MPa range. 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 some what 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 was studied by Pigeon, Aitcin, and KaPlante (1987) and Pigeon and Plante (1989). Their 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 1986).

2.2.4 Water

The requirement of water quality for High Performance Concrete is no more stringent than that for conventional concrete. Usually, water for concrete is specified to be of portable quality. This is certainly conservative but usually does not constitute a problem. However, cases may be encountered where water of lower quality must be used. In such cases, test concrete should be made with water and compared with concrete made with distilled water, or it may be more convenient to make ASTM C 109 mortar cubes. In either case, specimen should be tested in compression at 7 and 28 days. If those made with the water in question are at least equal to 90 percent of the compressive strength of the specimen made with distilled water, the water can be considered as per ASTM C 94 specifications.

Water for mixing and curing concrete should be reasonable clean and free from objectionable quantities of organic matter, silt, and Salts. Excessive impurities in mixing water may not only affect setting time and concrete strength, but may also cause efflorescence, staining, corrosion of reinforcement, volume instability, and reduced durability. Therefore, certain optional limits may be set on chlorides, sulphates, alkalis and solids in the mixing water or appropriate tests can be performed to determine the effect the impurity has no various properties. Some impurities may have little effect on strength and setting time, yet they can adversely affect durability and other properties. 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 high sulphate 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.

2.2.5 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 performance 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 performance 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 high quality work. The normal water-reducing admixtures are derived from salts of sulfonated lignin, hydrox 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.

Derived from naphthalene or melamine sulfonate formaldehyde, lingo-sulfonates, hydroxylated carboxylic acid, sulphonated melamine formaldehyde condensates and sulphonated formaldehyde condensates, the super-plasticizers are high molecular weight, anionic, surfactants with a large number of groups in the hydration chain. Normal water such as lingo-sulfonates, exhibit a high degree of cross-linkage and formation of spherical micro gel floc when used in a much larger than the recommended dosage. On the contrary, the linear molecules of super-plasticizers do not form micro gel flocs and are therefore much better dispersing agent for Portland cement-water system.

For obtaining good workability and in turn high compressive strength, use of a super-plasticizer can result in a water reduction 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 pozzolans 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.

2.3 Mix Proportions for High Performance Concrete

Only few mix design methods for high performance concrete have been developed to date. Most commonly, purely empirical procedures based on trial mixtures are used. The basic objective of concrete mix proportioning is to select the most practical and economical combination of material to produce concrete that will meet performance requirements for the specified conditions and use. It is important for the designer to understand the basic principles of mix proportioning.

This will ensure that the mix will possess the potential for acceptable workability, strength, durability, appearance, economy, and other characteristics unique for the particular application. The flow chart given in fig-1 shows the step-by-step procedure for selecting proportions for mix designs of high performance concrete.

The most common method of creating high performance concrete is to design and control the combination of cementatious material, aggregates, water and admixtures. Cementitious material include Portland cement, silica fume, fly ash, ground granulated blast furnace slag, or natural pozzolans. The important parameters in proportioning the high performance concrete are given in the succeeding paragraphs and flow chart for mix proportioning is given in fig 2.1.

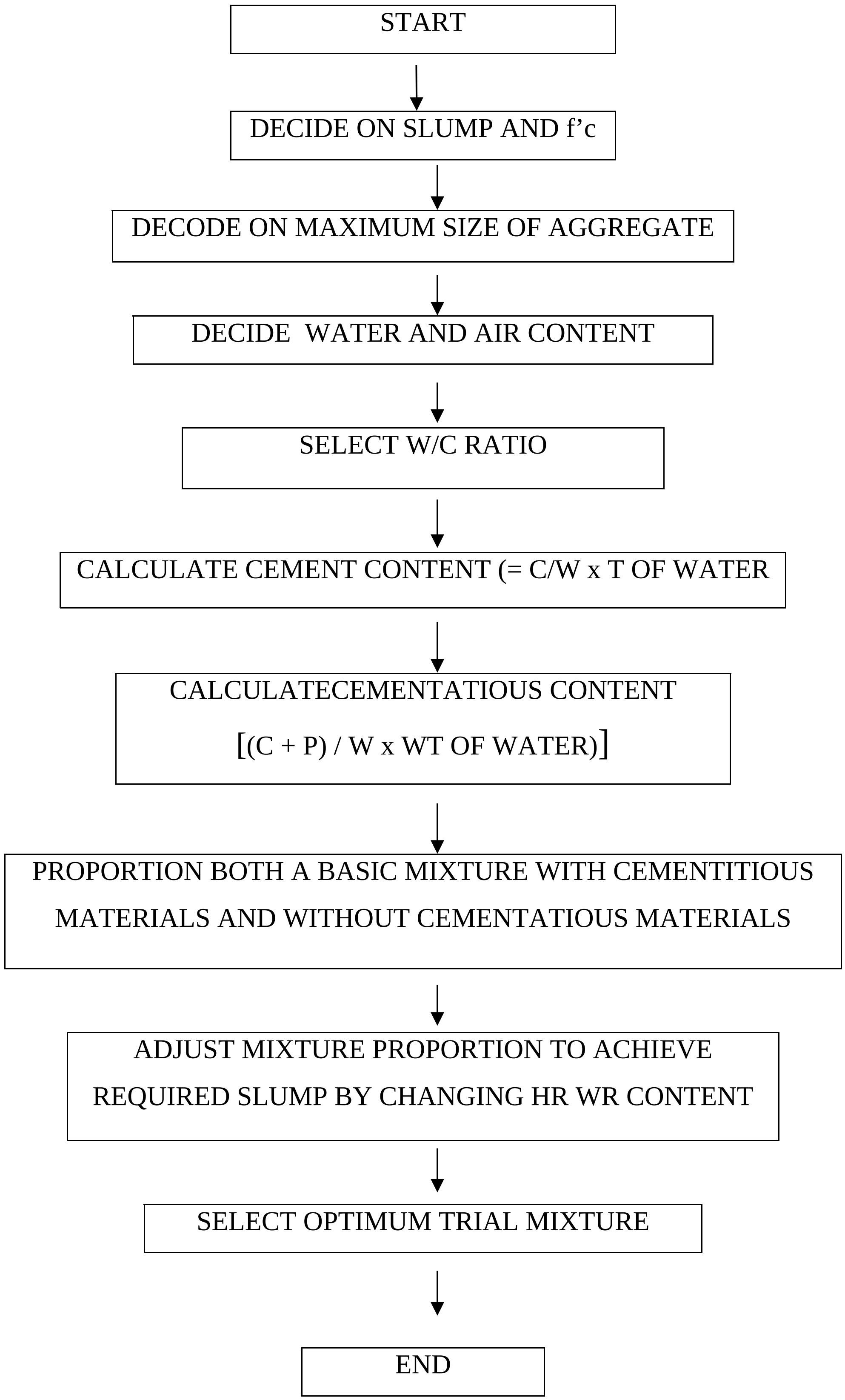

Fig 2.1 Flow Chart showing the step-by-step procedure for mix design of HPC

2.3.1 Parameters Affecting the Mix Proportioning

2.3.1.1Water / Cementitious Ratio

For normal strength concretes, mix proportioning is based to a large extent on the w/c ratio 'law '. For these concretes, in which the aggregate strength is much greater than the paste strength, the w/c ratio does indeed determine the strength of the concrete for any given set of raw materials. For high strength concretes, however, in which the aggregate strength of the cement-aggregate bond, are often the strength controlling factors, the role of the w/c ratio is less clear. To be sure, it is necessary to use very low w/c ratios to manufacture high strength concrete. However, the relationship between the w/c ratio and concrete strength is not as straightforward as it is for normal strength concrete.

2.3.1.2 Cementitious Materials Content

For normal strength concretes, cement contents are typically in the range of 590 to 930 pcf (350 to 550 kg/m^3). For high strength concretes, however, the content of cementitious materials (cement, fly ash, slag, silica fume) is higher, ranging from about 845 to 1090 pcf (500 to 650 kg/m^3). The quantity of supplementary cementing materials may vary considerably, depending upon workability, economy and heat of hydration considerations.

2.3.1.3 Supplementary Cementing Materials

As indicated earlier, it is possible to make high strength concrete without using fly ash, slag or silica fume. For higher strengths, however, supplementary cementing materials are generally necessary. In particular, the use of silica fume is required for strengths much in excess of 14,000 psi (98 MPa). In any event, the use of silica fume (which is now readily available in most areas) makes the production of high strength concrete much easier; it is generally added at rates of 5% to 10% of the total cementatious materials.

2.3.1.4 High Range Water Reducers

With very careful mix design and aggregate grading, it is possible to achieve strengths of about 14000 psi (98 MPa) without super-plasticizers. However, as they are readily available they are now almost universally used in high strength concrete, since they make it much easier to achieve adequate workability at very low w/cementatious ratios.

2.3.1.5 Ratio of Coarse to Fine Aggregate

For normal strength concretes, the ratio of coarse to fine aggregate (for a 0.55 in, 14 mm max size of aggregate) is in the range of 0.9 to 1.4. However, for high strength concrete, the coarse/fine ratio is much higher. For instance, Peterman and Carrasquillo recommended a coarse / fine ratio of 2.0.

2.3.1.6 Mixing

As stated previously, high – performance concretes are produced in the same way as usual concretes, using the same production equipment, except that the mixing sequence is usually longer. All equipment used to weigh and batch concrete ingredients must be accurate. Weighing devices must be calibrated regularly because it is essential that the carefully selected and controlled materials be weighted precisely in order to consistently obtain the targeted strength and workability. High – performance concrete mixtures are very sensitive to any variation in their proportions, especially in water content.

High performance concrete has been produced successfully in dry-batch plants. The transit mixers are loaded in two steps in order to obtain a very homogenous mixture. Several structures have been constructed using dry-batch a method yielding very well results however; it is easier to produce high-performance concrete in a ready-mix plant equipped with a central mixer. This mixer can be of the tilt or the horizontal pan type, with or without current mixing paddles.

Mixing times are usually longer for high performance concretes than for usual concretes, but it is difficult to give specific rules. The mixing time has to be adjusted on a case by case basis; Mixing is optimized so that any further increase in mixing time does not increase the homogeneity or the workability of the concrete. There is one rule to remember when mixing high performance concrete and that is the slump value should not be higher than 230 mm. High performance concretes with higher slump values are prone to segregate, unless their composition has been adjusted slightly.

2.3.1.7 Controlling the Temperature of Fresh Concrete

Control of the temperature of fresh concrete is very important in the case of high performance concrete, because temperature has major effects on its rheology. If the temperature of the concrete just after mixing is too high, say above 25^0C. Hydration is accelerated and it can be difficult to maintain the mix in a workable condition to ensure proper delivery and placing, except if the mix composition is modified to take into account this high initial temperature. Moreover, when the temperature of the concrete is too high, it can be difficult to keep a close control over the entrained air for air entrained mixes. On the other hand, if the mix is too cold, say below 10^0C, it must be remembered that liquid super-plasticizers are less effective in dispersing cement particle because their viscosity increases drastically as their temperature increase.

2.3.2 Quality Control and Testing

Conventional normal strength concrete is a relatively forgiving material; it can tolerate small changes in material, mix proportions or curing conditions without large chances in its mechanical properties. However, high strength concrete, in which all of the components of the mix are working at their limits, is not at all a forgiving material. Thus, to ensure the quality of high strength concrete, every aspect of the concrete production must be monitored from the uniformity of the raw materials to proper batching and mixing procedures, to proper transportation, placement, vibration and curing, through to proper testing of the hardened concrete.

The quality control procedures, such as the types of test on both the fresh and hardened concretes, the frequency of testing, and interpretation of test result are essentially the same as those for ordinary concrete. However, Cook has presented data which indicate that for his high strength concrete, the compressive strength results were not normally distributed, and the standard deviation for a given mix was not independent of test age and strength level. This led him to conclude that the quality control techniques used for low to moderate strength concretes may not necessarily be appropriate for very high strength concretes. To this date, however, separate quality control/quality assurance procedures for high strength concrete have not been developed.

2.3.2.1 Age at Test

Traditionally, the acceptance standards for concrete involve are strength determination at an age of 28 days. Although there is, of course, nothing magical about this particular test age, it has been used universally as the reference time at which concrete strength is reported. However, for high strength concrete, it has become common to determine compressive strength at 56 days, or even 90 days. The justification for this is that concrete in structures will rarely, if ever, be loaded to anything approaching its design strength in less than 3 months, given the pace of construction. The increase in strength between 28 to 56 or 90 days can be considerable (10% to 20%), and this can lead to economies in construction. It is this perfectly reasonable to measure strengths at later ages and to specify the concrete strength in terms of these longer curing times.

There are, however, two drawbacks to this approach. First, it can be misleading to compare the compressive strengths of normal and high strength concrete, if these are measured at different times. Of more importance there is a certain margin of safety when concrete strengths are measured at 28 days, since the concrete will generally be substantially stronger when it finally has to carry its design loads, perhaps at the age of one year for a typical high rise concrete building. If strengths are specified at later ages, this margin is reduced (by an unknown amount), and hence there is an implicit reduction in the factor of safety. And, of course, finding higher strengths at later test ages does not in any way imply that the concrete has somehow become better than a concrete whose strength was measured in the conventional way at 28 days.

2.3.2.2 Curing Conditions

In general, the highest concrete strengths will be obtained with specimens continuously moist cured (at 100% relative humidity) until the time of testing. Unfortunately, the available data on this point are ambiguous. Carrasquillo, Nilsson and Slate found that high strength concrete, moist-cured for 7 days and then allowed to dry at 50% relative humidity till 28 days showed a strength loss of about 10% hen compared to continuously moist-cured specimens. However, in subsequent work, Carrasquillo and Carrasquillo [29] found that up to an age of 15 days, specimens treated with a curing compound and allowed to cure in the field under ambient conditions yielded slightly higher strengths than moist-cured specimens. At 28 days moist-cured specimens and field cured specimen (with or without curing compounds) yielded approximately the same results, Only at later ages (56 and 91 days) did the strengths of the moist-cured specimen surpass those of the field-cured specimens treated with a curing compound. Similarly, Burg and Ost found that, when specimens that had been moist cured for 28 days were then subjected to air curing, their strengths at 91 days exceeded those of continuously moist-cured specimens; however, by 426 day, the continuously moist-cured specimens were from about 3% to 10% higher in strength than the air cured ones.

On the other hand, several investigators have reported that, as long as a week or so of moist curing I provided, subsequent curing under ambient conditions is not particularly detrimental to strength development. Peterman and

Carrasquillo have stated that the 28 day compressive strength of high strength concrete which has been cured under ideal conditions for 7 days after casting is not seriously affected by curing in hot or dry conditions from 7 to 28 days after casting.

Finally, contrary results ere reported by Mereno who indicated that air cured specimens were about 10% stronger than moist-cured specimens at all ages up to 91 days.

2.3.2.3 Mold Type for Casting Cylindrical Specimens & Specimen Size

ASTM C470: Molds for Forming Concrete Test Cylinders Vertically, describes the requirements for both reusable and single-use molds, and ASTM C31: making and Curing Concrete Test Specimens on the Field permits both types of mold to be used. However, it has long been known that different molds conforming to ASTM C470 will result in specimens with different measured strengths. This is true for both normal strength and high strength concretes. In general, more flexible molds will yield lower strengths than very rigid molds, because the deformation of the flexible molds during rodding or vibration leads to less efficient compaction than when using rigid molds. The experimental data largely bear this out. It should be noted that, whatever the mold materials, the molds must be properly sealed to prevent leakage of the mix water, if any significant leakage does occurs, the apparent strength will generally increase, because of the lower effective w/c ratio, and increased densification of the specimens.

For the standard 6 x 12 in. (150 x 300 mm) molds, Carrasquillo found that steel mold gave strengths about 5% higher than plastic molds, while Hester found about a 10% difference. Similar results were reported by Howard and Leatham. Peterman and Carrasquillo reported that steel molds gave strengths about 10% higher than those obtained with cardboard molds, and Hester showed that steel molds gave strength about 6% higher than molds.

On the other hand, Cook reported that good success was experienced on the use of single use rigid plastic molds. While Aitcin reports increasing use of rigid, reusable plastic molds. In addition, Carrasquillo and Carrasquillo have reported that for the similar 4 x 8 in. (100 x 200 mm) molds, there were no strength differences between steel, plastic or cardboard molds.

In view of above results, it would be prudent to use rigid steel mold whenever practicable, particularly for concrete strengths in excess of about 14000 psi (98 MPa), at least until more test data become available for the smaller molds.

For most materials, including concrete, it has generally been observed that the smaller the test specimen, the higher the strength. For high strength concrete, however, through this effect is often observed, there are contradictory results reported in the literature. It may be seen that the observed strength ratios of 4 x 8 in. (100x 200 mm) cylinders to 6 x 12 in. (150 x 300 mm) cylinder range from about 1.1 to 0.93. These contradictory results may be due to differences in testing procedures amongst the various investigators.

It must be noted that while for a given set of materials and test procedures, it may be possible to increase the apparent concrete strength by decreasing the specimen's size, this does not in any way change the strength of the concrete in the structure. One particular specimen size does not give 'truer' results than any other. Thus, one should be careful to specify a particular specimen size for a given project, rather than leaving it as a matter of choice.

2.3.2.5 Testing Machine Characteristics

In general, for normal strength concrete, the characteristics of the testing machine itself are assumed to have little or no effect on the peak load. However, for very high strength concretes the machine may well have some effect on the response of the specimen to load. From a review of the literature, Hester concluded that the longitudinal stiffness of the testing machine will not affect the maximum load, and this view is shred also by Aitcin. However, if the machine is not stiff enough, the specimens may fail explosively, and of course a very stiff machine (with servo controls) is required if one wishes to determine the post peak response of the concrete. On the other hand, Haster also reports that if the machine is not stiff enough laterally, compressive strengths may be adversely affected.

One must also be concerned about the capacity of the testing machine when testing very high strength concretes. Aiticin calculated the required machine capacities for different strength levels and specimen sizes, using the common assumption that the failure load should not exceed 2/3 of the machine capacity. Some of his results are reproduced in Table 2.4 below:-

Table 2.4 Machine Capacity for High Strength Concrete

Failure load			**Machine Capacity**	
Specimen size	*F'c=100* MPa	*F'c=150* MPa	*F'c=100* MPa	*F'c=150* MPa
100 x 200 mm	0.785 MN	1.18 MN	1.2 MN	1.75 MN
150 x 300 mm	1.76 MN	2.65 MN	2.65 MN	4.0 MN

Relatively few commercial laboratories are equipped to test high strength concrete, since a common capacity of commercial testing machine is 292500 lbs (1.3 MN). To test a 6 x 12 in. (150 x 300 mm) cylinder of 21400 psi (150 MPa) concrete requires a 9, 00,000 lb (4.0 MN) testing machine, and relatively few machines of this size are available in commercial laboratories. This then, is probably the driving force behind the move to the smaller 4 x 8 in. (100 x 200 mm) cylinders.

2.4 <u>Strength Properties of High Performance Concrete</u>

It is wrong to believe that the mechanical properties of a high performance concrete are simply those of a stronger concrete. Certainly there are cases when high performance concrete behaves simply as a stronger concrete, but there are also other cases when high performance concrete behaves quite differently. These differences in the mechanical behavior of high performance concrete and usual concrete result from their different microstructures, so an external load applied on the concrete does not necessarily develop the same stress field within the concrete and the materials does not respond in the same way to this stress field.

The cement paste microstructure has a great impact on the strength, permeability, and volumetric stability (resistance to plastic shrinkage, drying shrinkage, and creep) of high strength concrete. Factors affecting the microstructure of a paste are mixture proportions, temperature and humidity during curing, water/cement ratio, chemical and mineral admixtures, and amount of shear during mixing, and the degree of over mixing. Fly ash and blast furnace slag, in addition to reducing the heat of hydration at early ages, tend to reduce the effects of the preceding parameters on the formation of the paste microstructure. Silica fume has an accelerating effect on early hydration by reducing the effect of lignosulfonate retarders. Thus, the microstructure formation will be faster than expected when using the retarders. High strength concrete has a compact, extremely low void structure resulting from occupation of pores with pozzolanic cementitious materials. As a result concrete very low permeability concrete is produced which helps to resists freeze thaw attack, chemical attack, salt penetration, and corrosion of the embedded steel.

2.4.1 Compressive Strength

Obviously, the compressive strength of high performance concrete is higher than that of usual concrete, and it is not as easy as many people believe to measure properly it goes over 60 MPa. Unlike usual concrete, the water/cement law is only valid until the crushing strength of the coarse aggregate becomes the weakest link within high performance concrete. When coarse aggregates are no longer strong enough in comparison with the strength of the hydrated cement paste, the compressive strength of a high performance concrete does not increase significantly as the water / cement ratio decreases. The only way to increase the compressive strength of such a high performance concrete is therefore to use another type of coarse aggregate. When the coarse aggregate is strong enough, it is still impossible to state a general relationship between the water/cement ratio and the high performance concrete compressive strength that can be achieved because of the multiple factors influencing the relationship between f'c and the water/cement ration.

2.4.2 Modulus of Rupture and Splitting Tensile Strength

The direct measurement of the tensile strength of usual concrete is not easy because of the complicated set-up that must be used. Therefore, tensile strength is usually calculated using indirect measurement, such as the measurement of the modulus of rupture and /or the splitting tensile strength. Performing MOR and splitting tensile strength measurements does not present any special difficulties on the case of high performance concrete, so that the same set ups and procedures used for usual concrete can also be used for high performance concrete.

2.4.3 Modulus of Elasticity

It is suggested that rather than relying on theoretical and empirical models to predict the elastic modulus of a high performance concrete, it is better to measure it directly on specimens made under real field conditions. Rather than relying on generic formula, it would be better for important projects to determine the modulus directly for each high strength concrete proposed for use. Even for a given aggregate, different moduli can result from changes in mixture proportions, so aggregate specific and mixture specific are desirable.

2.4.4 Durability

Concrete durability, which was correlated with concrete strength for so long, can no longer be associated with it; owing to the technological progress in cement and concrete technology that has taken place in recent decades. Concrete durability is still associated with the concrete water/cement ratio, as it has always been, because the water /cement ratio represents the concrete parameter that reflects its compactness and permeability to aggressive agents.

By using super-plasticizers, it is now possible to make concretes with very low water/cement ratios, so they are as impervious as the most durable rocks. Moreover, as in high performance concretes, as there is not enough water available to hydrate all the cement grains fully, there is a fair reserve of anhydrated cement particles. This unhydrated cement play a very important role. If for any reason the environmental conditions are harsher than initially anticipated, or the concrete gets cracked, then they will hydrate as soon as any water penetrates the concrete. This means that the anhydrate cement has a potential for self healing.

When engineer realize that concrete must no longer be specified in terms of compressive strength but rather in term of its water/cement ratio, they will be able to solve the durability problem that has plagued concrete for so long. They will have to make sure that this potentially durable concrete is placed and cured correctly. There is no excuse for making concrete that is not durable. Low water /cement ratio concrete can be with or without entrained air. As for the extra strength offered by these durable concretes, designers will have to learn how to make the best use of them in their designs. It must be emphasized that the concrete skin always a critical role in concrete durability and that all things result in the improvement of the concrete skin has to be implemented in order to improve the life cycle of concrete structures.

2.5 Economics Of High Performance Concrete

The use of high performance concrete in high-rise structures, offshore platforms, and other special applications more than compensate for the increased cost of material and more rigorous quality control and assurance that are normally needed when high performance concrete is used. It was demonstrated that the cost of supporting 100,000 Ibs of service load is about $5 per storey in 1975 for

6000psi concrete in the overall structural system. It drops to $3.65 for 9000psi concrete. This rate of drop should not be affected by today's cost since labor and material costs continue to be proportional. The reduction in cost is due to drastic reduction in member size, particularly in columns.

2.5.1 Principal Factors Affecting Cost

Cost of any product is affected by a variety of factors not the least of which is supply and demand. But demand is generated by knowledge and familiarity. A good knowledge by the design engineer and the constructor of the material behavior and performance of various concretes is always a contributor to a better design. With familiarity, trust is generated leading to increased application. The principal factors which affect the production, utilization, and costing of high strength concrete can be summarized as follows:-

- Research and development
- Areas of application and performance requirements
- Codes, standards, and engineering specifications
- Selection of material components and the design mix
- Quality control and assurance in production

2.5.1.1 Research and Development

The studies have shown that a compact discourse of the vast research and development activities in the area of concrete materials is in progress, particularly over the past 10 years. It is evident that high strength concretes possess certain characteristics that differ from those of normal strength concretes, as influenced by internal changes caused by short-term and long-term loads and environmental conditions. Since the end product is a constructed system, the impact of material characteristics of high strength concrete on the code design expressions has to be established.

The usual assumption for normal strength concrete has been to consider that concrete and steel reinforcement strains are identical until the reinforcement starts to yield. This assumption seems to be equally true for high strength concretes, both in beams and columns. The compressive stress distributions directly related to the shape of the stress - strain curve in uniaxial compression. However, the stress-strain diagram for high strength concrete is almost linear up to failure as compared to normal strength concrete, which is essentially parabolic. This difference suggests that the equivalent rectangular block might not be accurate enough for design purposes if, in the case of beams, the members are over reinforced if they are prestressed.

No conclusive evidence exists at this time on the need for major changes in the provisions of the ACI 318 code parameters for design of very high strength concrete structures, namely, concretes with compressive strength exceeding 12000 psi (83 Mpa). But more research and development are needed on the effect of the reduced ductility in higher strength concrete on the design parameters, particularly those that are more affected by the concrete strength than by reinforcement contribution, such as shear, torsion, development length, and repeated loadings. Costs would thus be affected by the design requirements if they differ in the case of high strength concrete. Evidence thus far indicates that the factor of high strength does not seem to have a major impact on the current approach to design, with modifications made as more research results are available.

2.5.1.2 Areas of Application and Performance Requirements

The performance of a concrete constructed system is greatly affected by the environment in which the system is to be placed. More intense requirements are needed in zones of high temperature fluctuations and seasonal changes. These factors include freeze-thaw, shrinkage cracking, effects of deleterious chemicals, and acid rain. Other requirements are needed for concrete placed under water or concrete in arctic zones and in special structures such as offshore oil platforms.

The listed placement conditions and other factors require a judicious selection of the type of concrete and its constituents, as well as the particulars mix proportions that fit the needs of the particular environment. Different placement procedures, locations, availability of materials and levels of quality control and assurance are affected by each of these conditions. Thus, cost of productions, placement, and finishing would be determined by the impact of all these factors on the production of the finished product.

2.5.1.3 Codes, Standards, and Engineering Specifications

It is essential to have a thorough understanding of the standards and codes of the particular zone in which a structural system is to be constructed, be it a building, a bridge, a highway, a tunnel, an offshore platform, or another superstructure or substructure. Together with this necessary understanding by the designer, the need to be well informed with the state of the art in high strength concrete is particularly paramount in proportioning in nonstandard cases. The resulting specifications that are generated by the engineer will determine the cost index of high strength concrete in comparison with normal strength concrete.

2.5.1.4 Selection of Material Components and the Design Mix

Superior quality has to be sought in the selection of all components of the high strength concrete mix. This can be achieved by more stringent control on quantity batching, laboratory and field testing, and elimination of deleterious materials. Material selection can be affected by availability and location. Transportation costs can be factor in the cost of the finished product as the level of strength often determines the types of component materials that have to be used.

2.5.1.5 Quality Control and Assurance in Production and Workmanship

In order to achieve a high quality high strength concrete, a larger number of control tests have to be performed than in the case of normal strength concrete. Certified professional teams with experience in high strength materials should conduct or supervise these tests. Systematic sampling and periodic testing have to be done throughout the construction period. Testing procedures used for normal strength concrete might have to be updated for higher strength concretes. End specimen preparation is a typical example where end grinding produces better and more consistent results than end capping. Numerous standards exist by the American Society for Testing and Materials (ASTM) and the American Concrete Institute (ACI):

- ASTM C9.03.01:Testing High Strength Concrete
- ASTM C39: Compressive Strength of Cylinder Concrete Specimens
- ACI 363: High Strength Concrete
- Other standards such as from the CEB (Committee Euro International du Beton) and other codifying agencies.

Stringent controls, use of qualified personnel (ACI certified or equivalent) and strict adherence to testing requirements have an impact on the cost. The practice of choosing the lowest bidder has to be discouraged in favor of superior short-term and long-term quality, pre-qualified concrete suppliers, testing laboratories, and contractors.

2.5.2 Cost Studies and Comparisons

The affect of the numerous benefits influence cost nonuniformly. Conditions pertaining to each project, location, zone, season, execution duration, and the technical expertise of the filed teams have variable effects on the costs of the different components and the totality of a project. Particular savings are attained in using as high a concrete strength in columns as possible. This is due to the fact that compressive strength is the principal parameter resisting compressive loads. But savings in floor systems and in beams as will as principal bridge components are equally documented. This cost comparisons in the use of high strength concrete in several large scale projects are presented in the succeeding paragraphs.

2.5.2.1 High Rise Buildings

Extensive cost analyses by Moreno of using high strength concrete in buildings give cost comparisons for different compressive strength levels is shown in Table 2.5. The study examined several factors affecting the optimal deign of high-rise building frames. This factor included lateral forces, building drift, foundation type, and the itemized cost of the construction material. Estimates of the construction material costs were based on material cost per kip – 454 lb of axial gravity load for square column of sizes 20, 30 and 40 in. (51, 76 and 102 cm). The study did not included construction costs in column of unbraced frames subjected to lateral loads. The increase in cost of concrete from $80/yd^3$ for *f'c = 7000 psi (48 Mpa) to $ 129/yd*^{3} *for f'c = 14000 psi (96 Mpa)* seems to be more than offset by the drastic reduction in the reinforcement percentage.

Table 2.5 In Place Cost (1992) For Concretes Having 7000-14000 Psi Strengths

Type of Material	**Cost in Place ($)**
Reinforcement	760/ton
Concrete	
f'_c = *7000 (48)*	$80/yd^3$
f'_c = *9000 (62)*	85
f'_c = *11000 (76)*	104
f'_c = *14000 (96)*	123
Formwork	280

Table 2.5 is based on using columns 40 in x 40 in. (102 cm x 102 cm) tied to non-slender carrying 1000 kips (4450 KN). It should also be noted that the use of minimum reinforcement in the case of high strength concrete allows easier flow and compaction of the concrete in the member because of lack of congestion of the reinforcement leading to further reduction in labor costs.

2.5.2.2 Cost Comparisons as Affected by Loads and Height

A case study is presented from Nathan and Leatham for two high-rise building comprising five and fifteen stories. Spans used were 15, 25 and 35 ft. (4.6, 7.6 and 10.7 m). The pricing had factored in the cost of slender columns in unbraced frames subjected to lateral seismic loading.

The building is box type without shear walls and subjected to uniform loading. The range of uniform load was at three levels as seen in Table 2.6, namely, 50 psf (2394 Pa) representing residential occupancy, 100 psf (4788 Pa) representing store or manufacturing occupancy and 150 psf (6732 Pa) representing storage or heavy manufacturing facilities. All columns had a slenderness ratio exceeding 22 for unbraced frame. Table 2.6 gives the frame geometry and load combinations. Table 2.7 gives the column details that formed the basis of this study and the material costs per sq foot of contact area with the formwork is presented in table 2.8.

Table 2.6 Frame Load and Concrete Strength Data

Configuration	***f'c* (Ksi)**	
	5 Stories	**15 Stores**
15 ft span, 70 psf dead load		
50 psf live load		
4% lateral load	4, 8, 12	4, 8, 12
8% lateral load	4, 8, 12	4, 8, 12
100 psf live load		
4% lateral load	4, 8, 12	4, 8, 12
8% lateral load	4, 8, 12	4, 8, 12
150 psf live load		
4% lateral load	4, 8, 12	4, 8, 12
8% lateral load	4, 8, 12	4, 8, 12
25 ft span, 115 psf dead load		
50 psf live load		
4% lateral load	4, 8, 12	4, 8, 12
8% lateral load	4, 8, 12	4, 8, 12
100 psf live load		
4% lateral load	4, 8, 12	4, 8, 12
8% lateral load	4, 8, 12	4, 8, 12
150 psf live load		
4% lateral load	4, 8, 12	4, 8, 12
8% lateral load	4, 8, 12	4, 8, 12
35 ft span, 160 psf dead load		
50 psf live load		
4% lateral load	4, 8, 12	4, 8, 12

8% lateral load	4, 8, 12	4, 8, 12
100 psf live load		
4% lateral load	4, 8, 12	4, 8, 12
8% lateral load	4, 8, 12	4, 8, 12
150 psf live load		
4% lateral load	4, 8, 12	4, 8, 12

Table 2.7 Column Details

Description	**Column size**			
	12 in x 12 inc	**18 in x 18 in**	**24 in x 24 in**	**36 in x 36 in**
Form area(ft^2 of column area)	48	72	96	144
Column volume (Yd^3/12ft length)	0.44	1.00	1.78	4.00
Span Length (ft)				
5 Stories	15	25	35	-
15 Stories	-	15	25	35
Reinforcing steel (%)				
5 Stories				
4000 psi	8.00	8.00	8.00	-
8000 psi	5.92	5.43	4.65	-
12000 psi	4.37	3.38	1.97	-
15 Stories				
4000 psi	-	8.00	8.00	8.00
8000 psi	-	5.00	4.46	3.35
12000 psi	-	3.31	1.76	1.07

Table 2.8 Cost Analysis Comparison

Breakdown of costs ($/$yd^3$)	**Column size**			
	12 in x 12 in	**18 in x 18 in**	**24 in x 24 in**	**36 in x 36 in**
Five Stories				
4000 psi Formwork	359.68	233.28	170.64	-
Reinforcement	504.19	503.98	504.02	-
Column concrete	83.05	74.25	64.60	-
Floor slab concrete	0.00	0.00	0.00	-
Shoring equipment	0.00	0.00	0.00	-
Total	**946.92**	**811.51**	**739.26**	**-**

8000 psi Formwork	359.68	233.28	170.64	-
Reinforcement	355.36	325.83	278.41	-
Column concrete	96.15	87.35	77.70	-
Floor slab concrete	56.52	32.23	23.47	-
Shoring equipment	56.71	25.20	14.17	-
Total	**811.00**	**653.50**	**536.05**	**-**

Breakdown of costs ($/yd^3)	**Column size**			
	12 in x 12 in	**18 in x 18 in**	**24 in x 24 in**	**36 in x 36 in**
12000 psi Formwork	359.68	233.28	170.64	-
Reinforcement	262.42	196.18	114.25	-
Column concrete	114.85	106.05	96.40	-
Floor slab concrete	70.54	44.36	34.69	-
Shoring equipment	113.41	50.40	28.35	-
Total	**694.08**	**529.47**	**387.63**	**-**
Fifteen Stories				
4000 psi Formwork	-	233.28	170.64	108.72
Reinforcement	-	503.98	504.02	504.02
Column concrete	-	74.25	64.60	58.39
Floor slab concrete	-	0.00	0.00	0.00
Shoring equipment	-	0.00	0.00	0.00
Total	**-**	**811.51**	**739.26**	**671.13**
8000 psi Formwork	-	233.28	170.64	108.72
Reinforcement	-	300.14	258.78	194.36
Column concrete	-	87.35	77.70	71.49
Floor slab concrete	-	28.85	21.07	11.43
Shoring equipment	-	25.20	14.17	6.30
Total	**-**	**624.42**	**514.02**	**379.70**
12000 psi Formwork	-	233.28	170.64	108.72
Reinforcement	-	192.05	102.07	62.11
Column concrete	-	106.05	96.40	90.19
Floor slab concrete	-	36.12	28.86	17.49
Shoring equipment	-	50.40	282.35	12.60
Total	**-**	**517.10**	**369.62**	**265.91**

2.5.2.3 High Strength Concrete in Prestressed Bridge Girders

The same trend in cost saving in high rise buildings is also established for bridge construction. The basic cost per cubic yard obviously increases with the increase in compressive strength. But as in buildings, the cost increase is offset by the reduction in the volume of concrete required to construct the bridge. The cost of the prestressing strands, however, will not significantly change. This is because as the number of girders is reduced, the number of strands per girder has to be increased.

The most substantial saving in the use of high strength concrete comes from the reduction in nonmaterial costs associated with the girders. These include a reduction in labor costs in the production of the girders, transportation costs, erection costs, and overhead expenses. In effect, therefore it is the reduction in the number of girders in a particular project which substantially reduces the costs. A saving of $196.50/ft ($645/m) was achieved by using the 10000 psi (69 MPa) concrete in the bridge girder proportions. It is seen that the use of high strength concrete in the production of prestressed concrete girders enables the design and erection of more efficient, more cost-effective, and higher performance bridges.

CHAPTER – 3

EXPERIMENTATION DETAILS & TEST PROCEDURES

3.1 General

Strength of concrete may depend to a large extent on the properties of materials used therein, like crush, sand and especially on the characteristics of cementitious material such as silica fume (the material used as partial replacement of cement in the present investigation to achieve the high performance concrete.) Thus to atomize the High Performance Concrete it was necessary to carry out the testing of materials used in this study.

Testing was carried out in two phases: -

Phase- I (Testing of the constituent materials of concrete)

Here the three commonly used materials in the concrete were tested. These are:-

- Cement Ordinary Portland cement, designated as Type-I from Cherat cement Factory was used. Cement was tested for Setting Time, Fineness, Soundness, Specific Gravity and Compressive Strength.
- Fine aggregate: Lawerncepur being the major supply in the region, sand was used. The sand was tested for Sieve Analysis, Specific Gravity and water absorption.
- Coarse aggregates Coarse aggregates from Sargodha & Margala were used. These were tested for Grading, Moisture Content, Specific Gravity and Absorption, Crushing value.

Phase - II (Testing of concrete)

Four different replacement levels of cement i.e. 0%, 5%, 10%, 15% by silica fume were carried out and tested. Following properties of concrete, (fresh and hardened) were investigated in this research work.

- Workability
- Compressive strength
- Tensile strength
- Modulus of rupture
- Modulus of Elasticity

3.2 Constituent Materials

For the present investigations, the type of materials which have been used is illustrated in table 3.1 below:-

Table 3.1 Constituent Materials

Ser	Item	Description
1.	Cement	Ordinary Portland cement from Cherat Cement Factory
2.	Fine aggregate	Lawerncepur sand
3.	Coarse aggregate	Crushed stone from Sargodha & Margala
4.	Silica fume	Procured from SIKA & MBT Construction Chemicals.
5.	High Range Water Reducer	Procured from SIKA & MBT Construction Chemicals.

3.3 Testing of Cement

3.3.1 Setting Time

This test is performed to determine whether cement paste remains plastic long enough to permit normal placing without hampering finishing operations. Setting time of cement was measured by using Vicat apparatus, following (ASTM C19–92) specification, according to which the initial setting time should not be less than 45 min and final setting time not greater than 600 min. In our case initial setting time was found to be 220 minutes and final setting time was 540 minutes, which meet the specified requirements.

3.3.2 Fineness

Fineness of the cement affects the rate of hydration. Greater cement fineness increases the rate at which cement hydrates and thus accelerates strength development. The cement sample was sieved through No 200 sieve and the weight retained was found. It was 0.5% of the weight of cement sample, which is less than 10% as specified by ASTM C184–76).

3.3.3 Soundness

Soundness of hardened cement paste is its ability to retain its volume after setting. Soundness test on cement sample was carried out by Le-chatlier apparatus for finding the expansion of the cement in accordance with BS 4550 : Part3: Section 3.7. The expansion was found to be 3 mm, which is less than the maximum specified limit of 10 mm.

3.3.4 Specific Gravity

Specific gravity of the cement is not an indication of the cement's quality; its principal use is in mix design calculations. For the determination of specific gravity of the cement sample, procedure as laid down in ASTM C 188 was followed according to which the specific gravity ranges from 3.10-3.15. Le-Chattlier flask and kerosene oil free of water was used in this test and the specific gravity of cement was found to be 3.10, which is within the specified limits.

3.3.5 Compressive Strength

Compressive strength test is the final check on the quality of the cement. The test was performed in order to determine whether the cement confirms to standard specification or not. The strength of cement was determined according to BS 4550: Part3: Section 3.4 and the results obtained meet the specified requirements of the relevant standard are shown in Table 3.2 below:-

Table 3.2 Summary of Test Results on Portland Cement

Ser	Test	Results	Standards
1.	Standard Consistency (%)	31.5	25
2.	Initial setting time (min) Final setting time (min)	220 540	>45 <600
3.	Compressive strength (psi) 3 days 7 days 28 days	 2200 3650 5800	 <1800 <3400 <5200
4.	Soundness (Le-Chtlier's apparatus)(mm)	3	>10
5.	Specific gravity	3.10	3.10

3.4 <u>Testing of Fine Aggregate</u>

3.4.1 Sieve Analysis

Sieve analysis is carried out to determine the grain size distribution, hence the fineness modulus. Fineness modulus indicates the relative fineness of aggregates. It is an experimental number use to classify the fine aggregates. The value of fineness modulus varies from 2.3 to 3.1, coarser the sand higher the number. Sieve analysis of the sand was carried out according to BS 882:1973. The fineness modulus of sand was 2.96 thereby indicating coarser sand and the results are shown in table 3.3. The grading curve of the sand is shown in fig 3.1, which shows that it is well within the specified limits.

Table 3.3 Grading of Fine Aggregates

Ser	Sieve Size	%Retained
1	#4	0
2	#8	18
3	#16	27.5
4	#30	17.5
5	#50	22
6	#100	10.5
7	#200	4.5

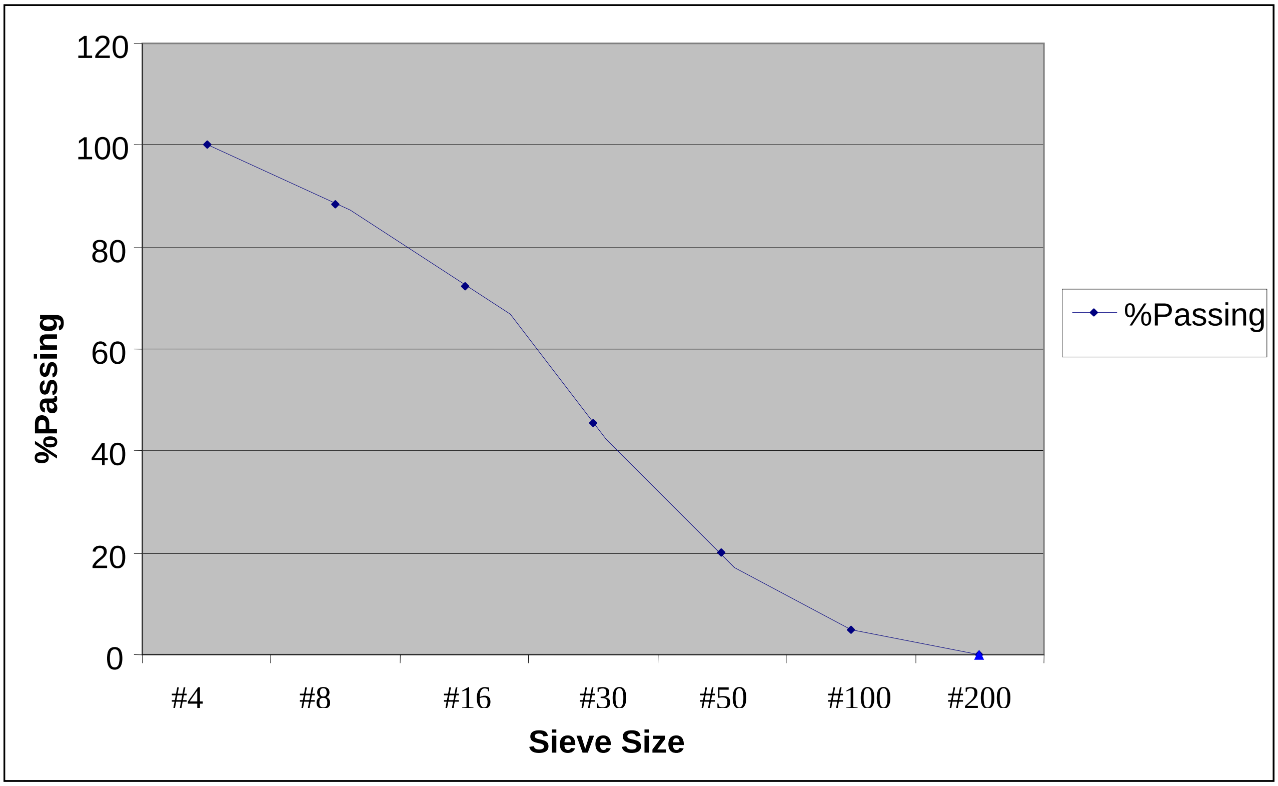

Fig 3.1 Grading Curve of Fine Aggregate

3.4.2 Specific Gravity and Absorption

specific gravity values are used in mix proportioning calculations to fined absolute volume that a given weight of material will occupy in the mix. The bulk specific gravity (oven dried) was determined according to ASTM C 128–79 and was found to be 2.63. The absorption after 24 hours immersion in water was 1.1%. The results are given in table 3.4, showing that the sand is suitable for high performance concrete.

Table 3.4 Properties of Fine Aggregate

Ser	Property	Result
1	Fineness Modulus	2.96
2	Bulk specific gravity (SSD)	2.65
3	Bulk specific gravity (Oven dry)	2.60
4	Water Absorption	1.1%
5	Apparent specific gravity	2.69

3.5 Testing of Coarse Aggregate

3.5.1 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 3.5. Grading curve for the coarse aggregate is shown in figure 3.2, which is well within the specified boundaries.

Table 3.5 Grading of Coarse Aggregate

S.No	Sieve Size	%Passing
1	#1/2”	100
2	#3/8”	92
3	#4	20
4	#8	5
5	#16	4

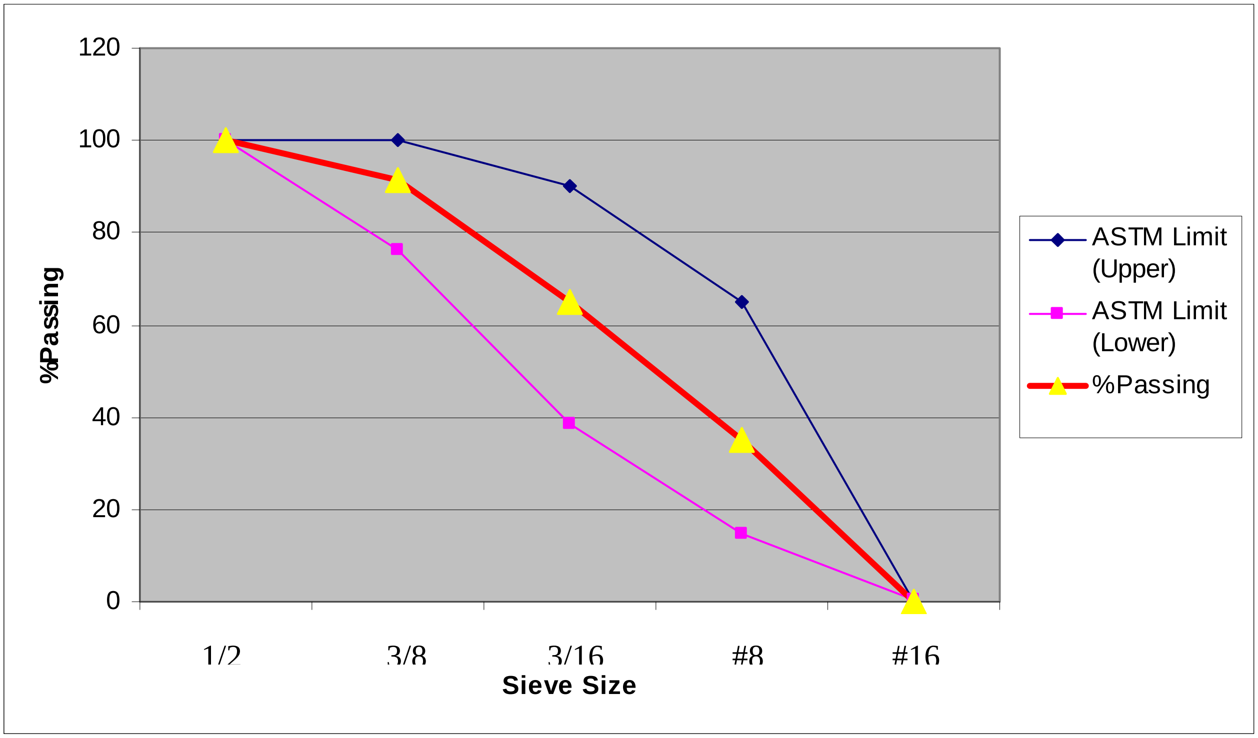

Fig 3.2 Grading Curve of Coarse Aggregate

3.5.2 Specific Gravity and Absorption

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 2.80 of Sargodha and 2.60 for Margala. This shows that the Sargodha crush is stronger than the Margala crush and suitable for high performance concrete.

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% to 8%. Good aggregates will normally have a value less than 1%. The absorption was found to be 0.05% for Sargodha which shows the crush is almost dry and 0.99% for Margala which is also good.

3.5.3 Crushing Value

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 10.2% for Sargodha and 23.5% for Margala. This shows that Sargodha crush is much stronger than Margala. Properties of Coarse Aggregate are given in table 3.6 below:-

Table 3.6 Properties of Coarse Aggregate

Ser	**Property**	**Results**	
		Sargodha	**Margala**
1	Bulk specific gravity Bulk specific gravity	2.8	2.6
2	Water absorption%	0.05	0.99
3	Crushing value%	10.2	23.5
4	Impact value%	7.25	16.2
5	Abrasion%	10.8	20.05

3.6 <u>Concrete Testing</u>

3.6.1 Concrete Mixes Test Specimens selected for present study

For the investigation of various properties of concrete three trial mixes were prepared and tested under standard laboratory conditions. The mix-I showing intermediate strength due to lowest cement content and lower coarse to fine aggregate ratio. The mix-II giving the best results had moderate cement contents as well as coarse to fine aggregate ratio and was selected for detailed laboratory investigations. The mix-III showing lowest strength due to excessive cement content and higher coarse to fine aggregate ratio. Excessive cement causes cracking of concrete due to higher heat of hydration. Low w/c ratio is pre requisite to achieve the higher compressive strength, therefore the w/c ratio was kept minimum i.e. 0.25. To make these mixes workable, high range water reducers were used. The test results of these mixes with the selected replacement levels were compared with the identical plain mix of same proportions, using only cement. Detail of the trial mixes and results are shown in table 3.7 below:-

Table 3.7 Trial mix results.

Ser	**Mix #**	**7 Days Compressive Strength (psi)**		**Remarks**
		Basic Mix	**5% SF**	
1	Mix –I	4280	6950	
2	Mix – II	4420	7400	
3	Mix – III	4100	6750	

<u>Test Specimens</u>

For the purpose of testing, following types of specimen were prepared and tested:-

- Compressive Test 6" X 12" Cylinders.
- Split Cylinder Test 6" X 12" Cylinders.
- Modulus of Rupture Test 4" X 4" X 15" Prisms.
- Modulus of Elasticity Test 6" X 12" Cylinders.

3.6.2 Mixing And Casting

The samples were prepared as per the guideline and recommended practice for measuring, mixing, transporting and placing of concrete (ACI–304–73). To study the compressive and split cylinder strength of concrete, three 6" x 12" cylinders were cast for test and trial at each condition of at replacement levels of cement by silica fume (0%,5%,10%&15%) and samples 7 days, 14 days and 28 days. Same procedure was adopted for determination of flexure strength but prisms with the size of 4" x 4" x 15"were cast from the same mix. Detail of the samples are given in table 3.8 as below:-

Table 3.8 Detail of Samples for Each Series

Ser	Tests	Crush	Basic Mix		5% Silica Fume		10% Silica Fume		15% Silica Fume	
			Cyl	**Prism**	**Cyl**	**Prism**	**Cyl**	**Prism**	**Cyl**	**Prism**
1.	Compressive Strength	**Sargodha**	9	-	9	-	9	-	9	-
2.	Tensile Strength		9	-	9	-	9	-	9	-
3.	Modulus of Rupture		-	9	-	9	-	9	-	9
4.	Modulus of Elasticity		9	-	9	-	9	-	9	-
Total			**27**	**9**	**27**	**9**	**27**	**9**	**27**	**9**
1.	Compressive Strength	**Margala**	3	-	3	-	3	-	3	-
2.	Tensile Strength		3	-	3	-	3	-	3	-
3.	Modulus of Rupture		-	3	-	3	-	3	-	3
4.	Modulus of Elasticity		3	-	3	-	3	-	3	-
Total			**9**	**3**	**9**	**3**	**9**	**3**	**9**	**3**

TOTAL

Cylinders = 144 + 36 (Trial batch)
Prism = 48

3.6.3 Consolidation and Finishing

Since the high strength concrete mix were very sticky therefore normal rodding procedure for consolidation was not found satisfactory. Due to this the combination of external and internal vibration method of consolidation was adopted. Vibratory table was used as external and vibrator machine was used as internal method of vibration. It was found that the combined method of external and internal vibration of each layer was more effective. Proper care was taken to ensure smooth surfaces, both at top and bottom.

3.6.4 Curing and Capping

The specimens were de-molded after 24 hours of casting and submerged in the water for next 24 hours. The specimens were than wrapped in jute bags and were given water bath 5 to 6 times a day. These conditions were maintained till a day prior to the testing of specimens.

At the time of casting of specimens, all efforts were made to smooth the top surface of the cylinders with the help of trowel, but true plane surface was difficult to achieve. The uneven top surface results in non-uniform stress distribution thus results in premature failure of specimens. In order to over come the problem of uneven top, capping procedure of ASTM C617–87 was followed.

3.6.5 Test Procedures

3.6.5.1 Workability

The ease with which concrete can be placed, consolidated and finished without segregation and bleeding. Workability of the concrete was measured in terms of slump which was determined for each batch following the procedure as laid down in ASTM C143–78.

3.6.5.2 Compressive Strength

Compressive forces in material act in the same manner as atomic bonding, forcing atoms together and this action in itself can not cause failure. However, compression induces shear stresses and tensile strain leading to tensile stress by the Poisson's ratio effect. Depending on the material type, specimen shape and loading arrangement, compression may cause shear or tensile failure or some combination of the two. For determining the compression strength of specimens

ASTM Standard lays down procedures which are internationally acceptable for quality control of concrete proportioning, mixing, placing operations; determination of compliance with specifications; control for evaluating effectiveness admixtures and similar uses. This test method consists of applying a compressive axial load to mould cylinders or cores at a rate which is with in a prescribed range until failure occurs. The compressive strength of the specimen is calculated by dividing the maximum load attained during the test by cross-section area of the specimen. Relevant ASTM specifications for making and testing of specimen are given below:-

- ASTM C192–90 Practice for making and curing concrete test in the laboratory.
- ASTM C39–86 Compressive strength of cylindrical concrete specimens.
- ASTM C617–87 Practice for capping cylindrical concrete specimens.
- ASTM C470–87 Moulds for forming concrete test cylinders vertically.

3.6.5.3 Tensile and Flexural Strength

Flexural strength is developed most commonly in beams and slabs as a result of loads, temperature changes, shrinkage, and in some cases moisture changes. For normal strength concrete, the tensile strength develops more quickly than the compressive strength and is usually about one-tenth the compressive strength at ages up to about 14 days, falling to about 5 percent at later ages. Behavior of tensile strength in high performance concrete is still under investigation and discussion. Most of the researchers report that tensile strength in high performance concrete stays within the range of 1/10 to 1/15 of the compressive strength. The ratio of tensile strength to the compressive becomes smaller as the compressive strength increases. The beam test for flexural tension and split cylinder test are the simplest methods for determining the tensile strength.

3.6.5.4 Splitting Tensile Strength

The test method (ASTM Method C496–90) measures the splitting tensile strength of specimens by the application of a diametrical compressive force on cylindrical concrete specimen placed with its axis horizontal between the platen of testing machine. The splitting strength is calculated as follows:-

a. f_{sp} = 2P/ñ LD

b. Where in consistent units

c. f_{sp} = splitting tensile strength,

d. P = maximum applied load,

e. L = Length

f. D = diameter.

The test is simple to perform in determining the tensile strength. Normally outer surface of cylinder are not uniform therefore in order to transfer properly distributed load strip of ply wood sheet is used.

3.6.5.5 Modulus of Rupture

Modulus of rupture also known as flexural tension is the theoretical maximum tensile stress reached in the bottom fiber of the test beam. ASTM Methods C192 and C31 describe the procedures for making flexural specimens for the splitting tensile strength test in the laboratory and in the field. ASTM Method C31 stipulates that the length of the beam should be at least 2" longer than three times its depth and that its width should not be more than one and half times its depth. The minimum depth or width should be at least three times the maximum size of aggregate. A typical specimen used would be 4"x4"x15" and is tested using third-point loading. For calculation of modulus of rupture the requirement of ASTM Standard C78–84 are similar to those of BS 1881: Part4: 1970. If the fracture occur within the central one third of the beam the modulus of rupture is calculated on the basis of ordinary elastic theory, and is therefore given below:-

.f_r = $PL / (bd^2)$

Where P = The maximum total load on the beam

L = Span

B = Width of the beam

D = Depth of the beam

If the fracture occurs outside the load points, i.e. say at a distance a from the near support, a being measured along the centre line of the tension surface of the beam, then the modulus of rupture is given as under.

$$.f_r = 3P\ a / (bd^2)$$

3.6.5.6 Modulus of Elasticity

A body, which regains its original dimensions after enduring stress, is said to be elastic. A quantitative measure of elasticity is the ratio of stress to corresponding strain. Robert Hook in 1678 (13) discovered that for many materials this ratio is constant over a fairly wide range of stress. This ratio is termed the modulus of elasticity, and it has become one of the most commonly used parameters to describe material properties even though many materials do not exhibit a linear stress-strain relationship.

The ASTM (C469-87a) is a standard test method for static modulus of elasticity of concrete. It stipulates a chord modulus between two points on the stress strain curve. This method provides a stress to strain ratio value and a ratio of lateral to longitudinal strain for hardened concrete at whatever age and curing condition may be designated. In this test procedure modulus of elasticity is calculated to the nearest 50,000 psi as follows: -

E_c = $(S_2 – S_1) / E_L – 0.000050$.

E_c = Chord Modulus of Elasticity, psi.

S_1 = Stress corresponding to longitudinal strain E_L of 50 millionth psi.

S_2 = Stress corresponding to 40% of ultimate applied load, psi.

E_L = Longitudinal strain produced by stress S1.

CHAPTER – IV

RESULTS AND DISCUSSION

4.1 General

Results presented in this discussion are based on testing of 84 compression specimens, 48 tensile specimens, 48 elasticity specimens and 48 flexural specimens. In all the mixes the mix design was kept constant and only the replacement level of cement with silica fume was varied from 5% to 15%. Results of these samples are compared with simple concrete. The comparison of concrete properties i.e. compression, tension, flexure and elasticity resulting from partial replacement of cement with silica fume are reviewed. Test results of concrete in fresh and hardened state are discussed in the succeeding paragraphs.

4.2 Workability of Concrete

The workability for various mixes, for specified replacement levels of Portland cement by silica fume, maintaining a constant water cement ratio was measured by slump test. Test results are shown in table 4.1 and graphically represented in fig 4.1. During the course of action the following were observed.

Table 4.1 Workability of Concrete

Ser	% Replacement of Silica fume	Slump (mm)
1.	0%	70
2.	5%	55
3.	10%	40
4.	15%	25

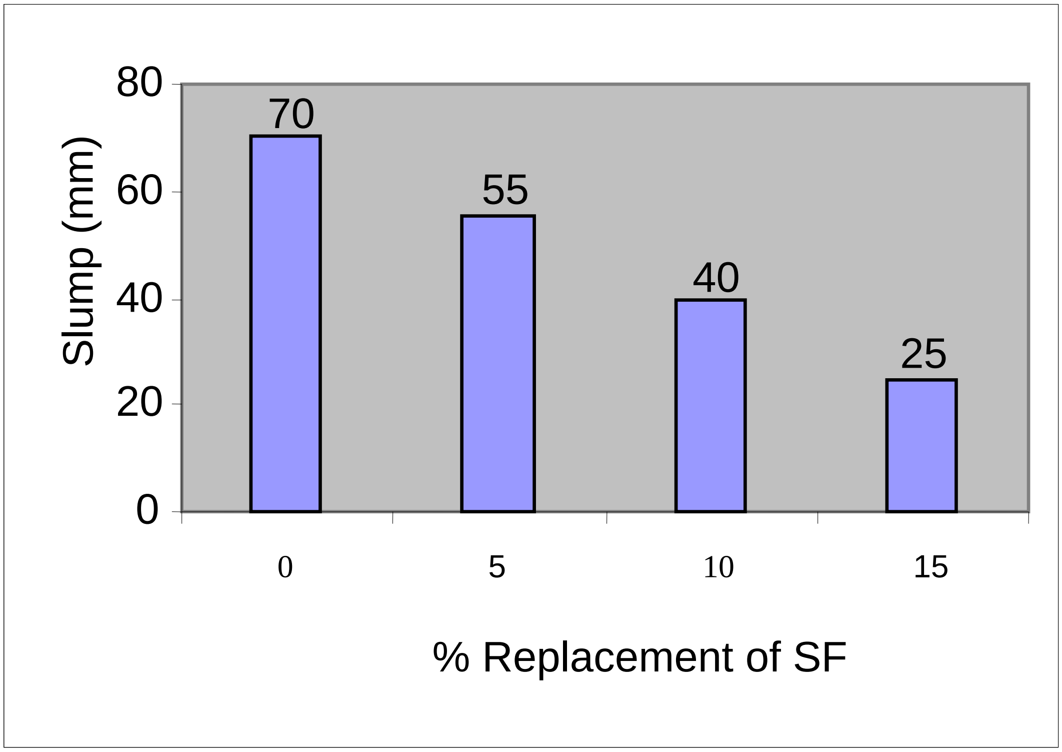

Fig 4.1 Workability of Concrete

- As evident from the results there was a gradual decrease in the workability of concrete with increasing the percent replacement of cement by silica fume. This is a clear indication that silica fume added to concrete itself increases water demand.
- During molding of test specimens and handling of silica fume mixed concrete, concrete specimens reflected non-plasticizing and sticky effect and it was pronounced for more than 10% of silica fume.
- The equal weight of silica fume has more volume than cement because of difference in their specific gravities. Therefore, replacement by weight resulted in a considerably greater volume of the cementitious material as the specific gravities of cement and silica fume are 3.10 and 2.2 respectively.

4.3 <u>Compressive Strength of Concrete</u>

Test results of the compressive strength of concrete are summarized in table 4.2 & 4.3 and graphically represented in fig 4.2, 4.3 & 4.4. On examining the different concrete mix by varying the % replacement of cement with silica fume (o%, 5%,10%& 15%) following observations are made.

Table 4.2 Summary of Test Results of Compressive Strength (Sargodha)

Ser	% Replacement of SF	Crush	Compressive Strength (psi)		
			7 Days	14 Days	28 Days
1.	0%	Sargodha	4890	5550	6530
2.	5%		7336	8690	10050
3.	10%		9050	10640	12230
4.	15%		9740	11370	13070

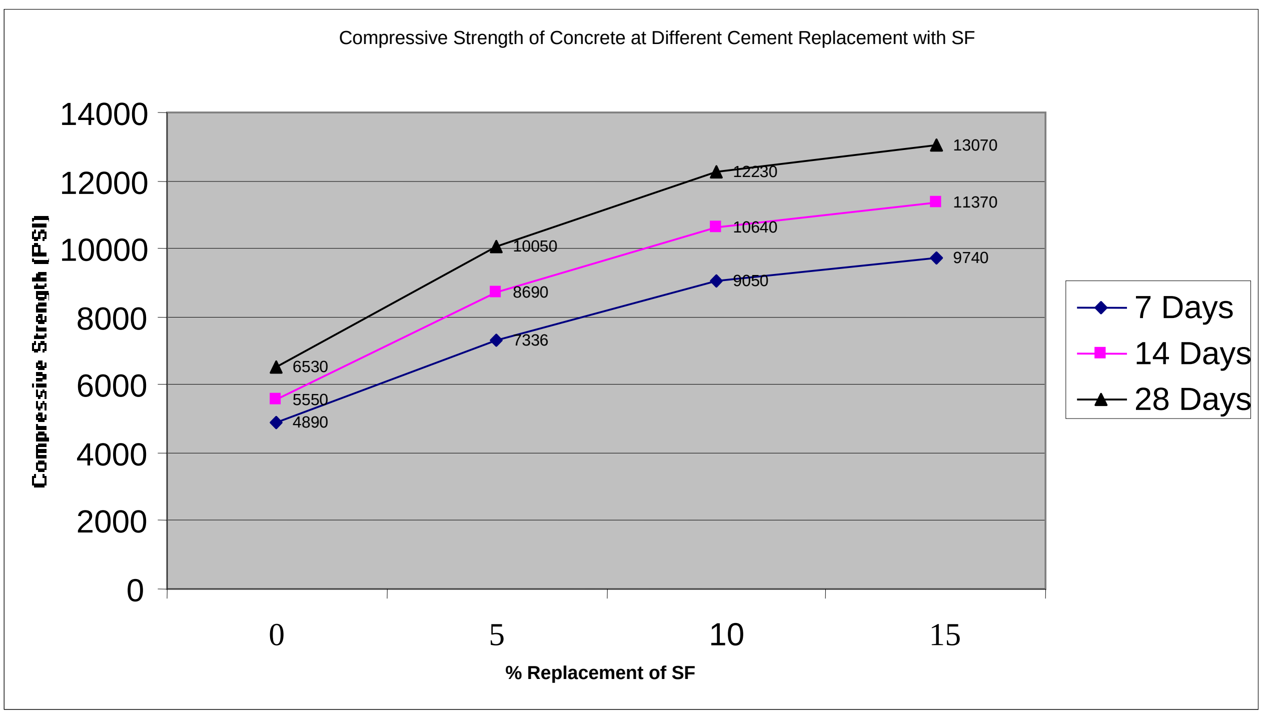

Fig 4.2 Compressive Strength of Concrete (Sargodha)

Table 4.3 Summary of Test Results of Compressive Strength (Margala)

Ser	% Replacement of SF	Crush	Compressive Strength (psi)		
			7 Days	14 Days	28 Days
1.	0%	**Margala**	4480	5080	5980
2.	5%		5870	7040	8385
3.	10%		6860	7840	9020
4.	15%		7100	8200	9470

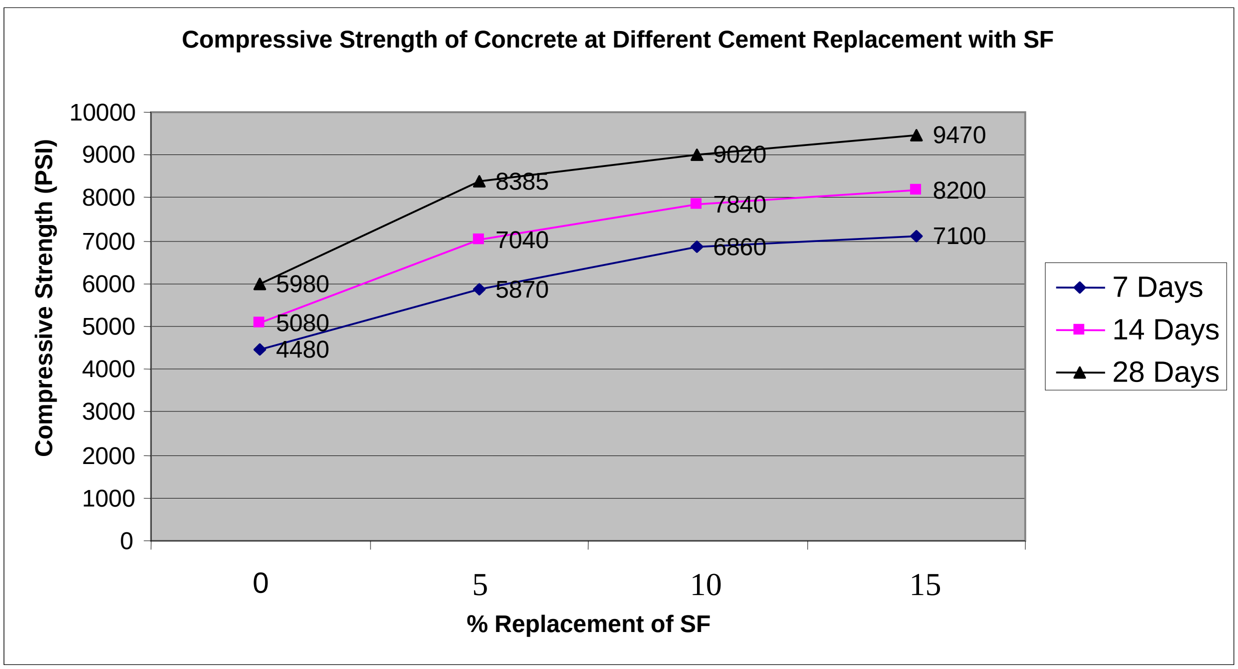

Fig 4.3 Compressive Strength of Concrete (Margala)

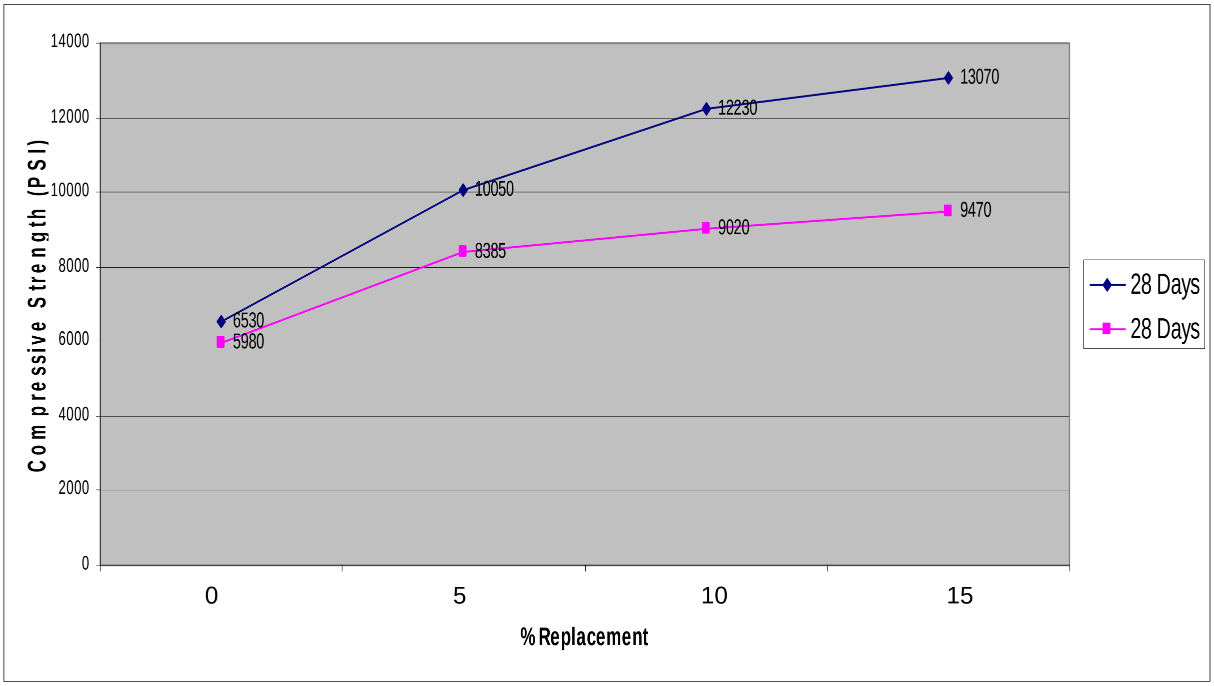

Fig 4.4 Comparison of Compressive Strength b/w Sargodha & Margala

- Rapid Increase in early age (7 days) strength was observed as the replacement level was increased from 5 % to 15 %. Whereas there was slow rate of gain of strength after 7 days.
- Compressive strength increases as the % replacement of cement by silica fume is increased but the increase in strength is different at different ages of concrete i.e. more % increase in 7 days strength and lesser in 28 days strength. This effect can be more clearly viewed from the graphs.
- Another important aspect which was observed that the compressive strength increase was more in case of concrete incorporating Sargodha crush as compared to the one incorporating Margala crush. The comparison of compressive strengths of both the concrete incorporating Margala as well as Sargodha is shown in fig 7.
- The most important aspect which was observed that the difference between the ultimate compressive strengths at partial replacement

levels of 10%&15% is small, thereby 10% partial replacement level is ‘’optimum’’.

4.4 Tensile Strength of Concrete

Test results of the tensile strength of concrete are summarized in table 4.4 & 4.5 and graphically represented in fig 4.5, 4.6 & 4.7. On examining the test results of splitting tensile strength the following observations are made.

Table 4.4 Summary of Test Results of Tensile Strength (Sargodha)

Ser	% Replacement of SF	Crush	Tensile Strength (psi)		
			7 Days	14 Days	28 Days
1.	0%	**Sargodha**	376	425	505
2.	5%		564	665	760
3.	10%		690	770	890
4.	15%		745	825	920

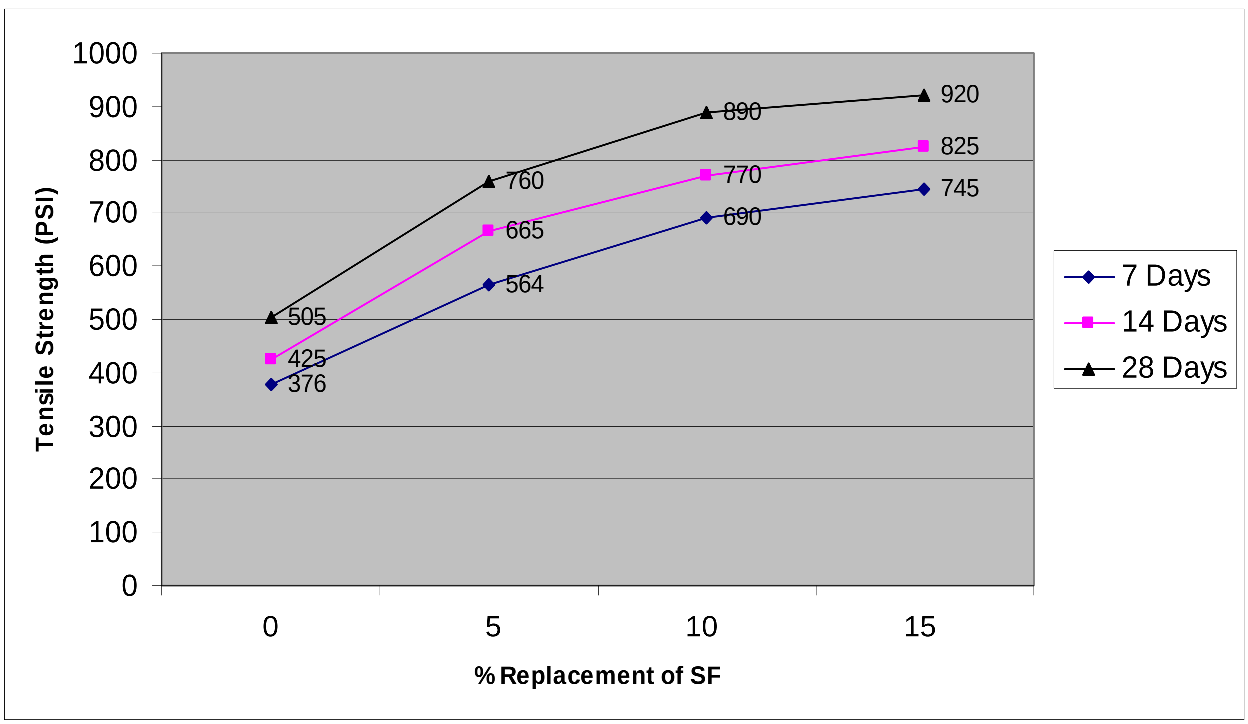

Fig 4.5 Tensile Strength of Concrete (Sargodha)

Table 4.5 Summary of Test Results of Tensile Strength (Margala)

Ser	% Replacement of SF	Crush	Tensile Strength (psi)		
			7 Days	14 Days	28 Days
1.	0%	**Margala**	-	-	465
2.	5%		-	-	650
3.	10%		-	-	690
4.	15%		-	-	730

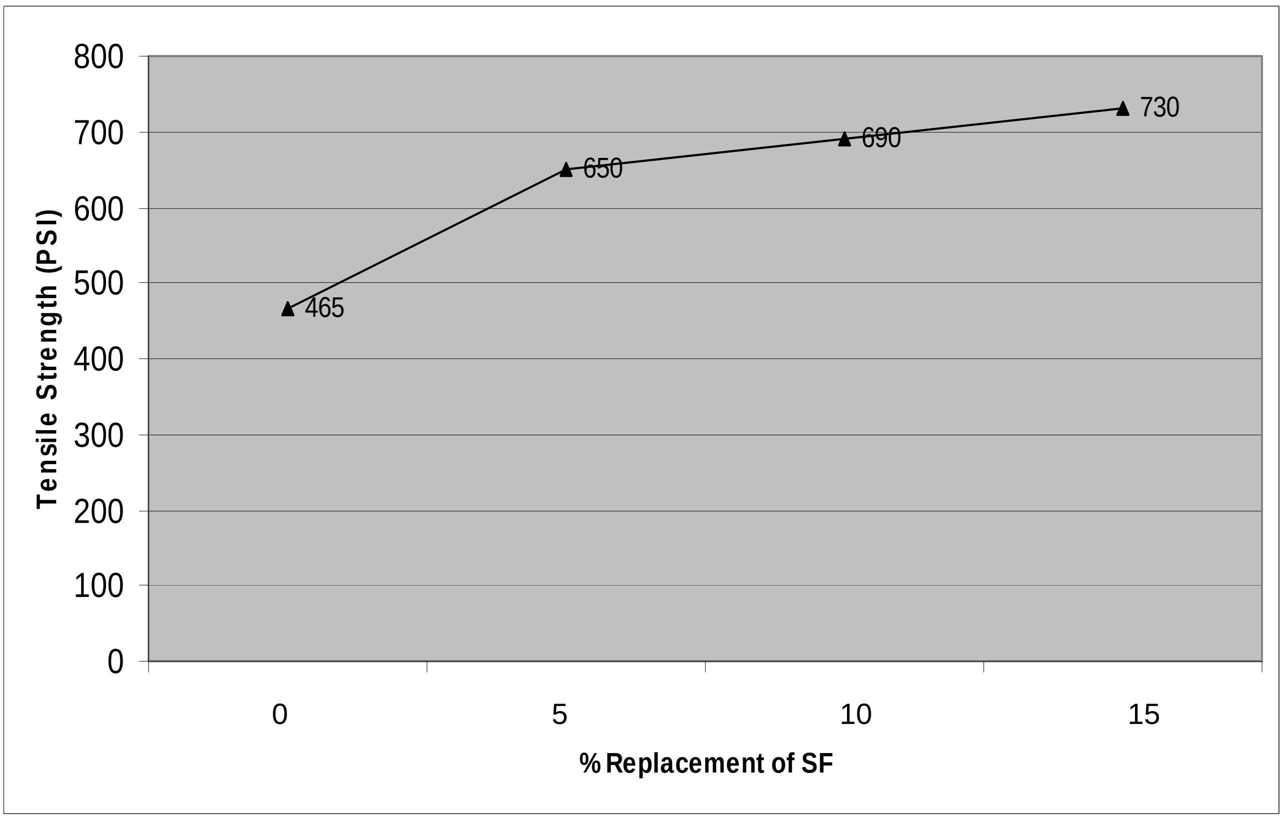

Fig 4.6 Tensile Strength of Concrete (Margala)

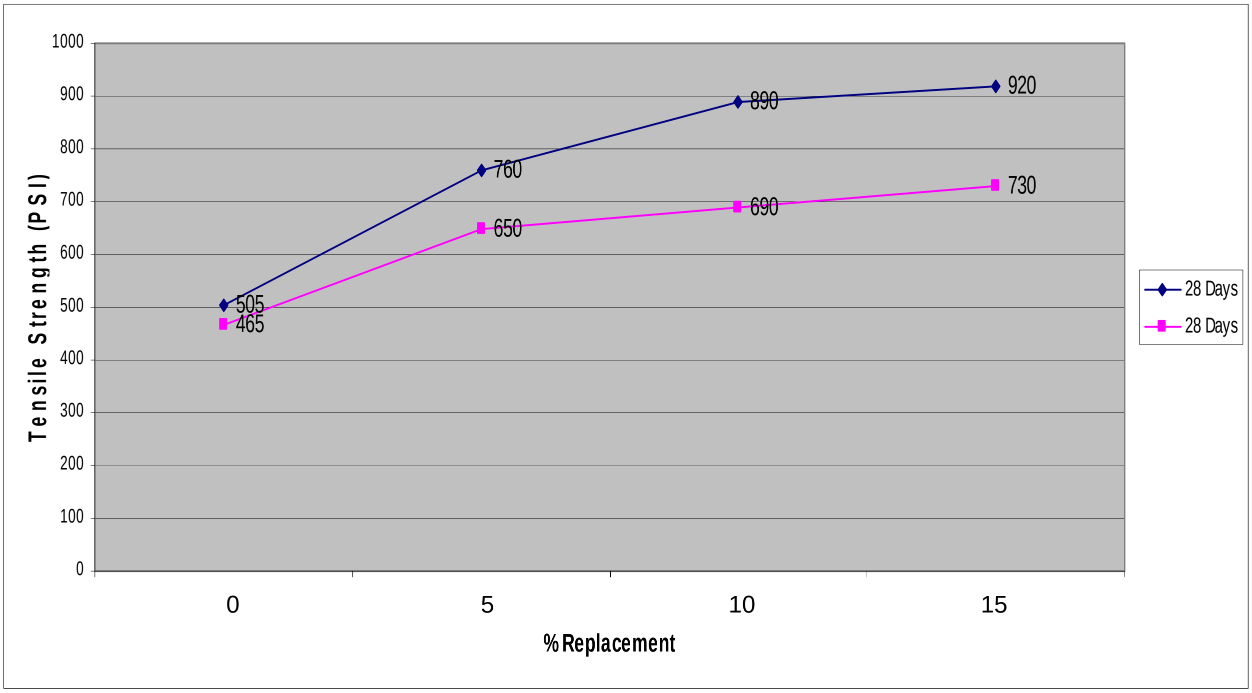

Fig 4.7 Comparison of Tensile Strength of Concrete b/w Sargodha & Margala

- An increase in tensile strength was noticed as the replacement level was increased from 5% to 15%. However the increase in tensile strength is less pronounced as compared to compressive strength.
- From the test data it was observed that the concrete of higher compressive strength specially the one incorporating Sargodha crush showed higher tensile strength. However the increase in tensile strength is not proportional to the compressive strength. In normal strength concrete the tensile strength is generally 10% of compressive strength but this was found to be conservative in high performance concrete.
- An empirical relationship in terms of compressive strength recommended by the ACI committee-363 to determine the splitting tensile strength is given by:

$$\boldsymbol{f}\mathbf{ct} = \mathbf{7.4x}\ [\ \boldsymbol{f}'\mathbf{c}\ ]^{0.5}\ \mathbf{(psi)}$$

Where, $f$ct and f'c are splitting tensile strength and compressive strength respectively.

- Based on experimental study, the values obtained for K ranges from 7.5 to 8 as given below:-

$$\boldsymbol{f}\mathbf{ct} = \mathbf{K\ X}\ [\ \boldsymbol{f}'\mathbf{c}\ ]^{\mathbf{0.5}}\ \mathbf{(psi)}$$ Where, K ranges b/w 7.5 to 8

4.5 Flexural Strength of Concrete

Flexural strength of concrete or modulus of rupture is measured by a beam flexural test and generally taken to be more reliable indicator of the tensile strength of concrete. Test results of flexural strength of concrete are summarized in table 4.6 & 4.7 and graphically represented in fig 4.8, 4.9 & 4.10. During the course of testing and from analysis of test results it is found that:

Table 4.6 Summary of Test Results of Modulus of Rupture (Sargodha)

Ser	**% Replacement of SF**	**Crush**	**Modulus of Rupture (psi)**		
			7 Days	14 Days	28 Days
1.	0%	**Sargodha**	575	650	760
2.	5%		810	975	1145
3.	10%		1005	1190	1335
4.	15%		1060	1250	1440

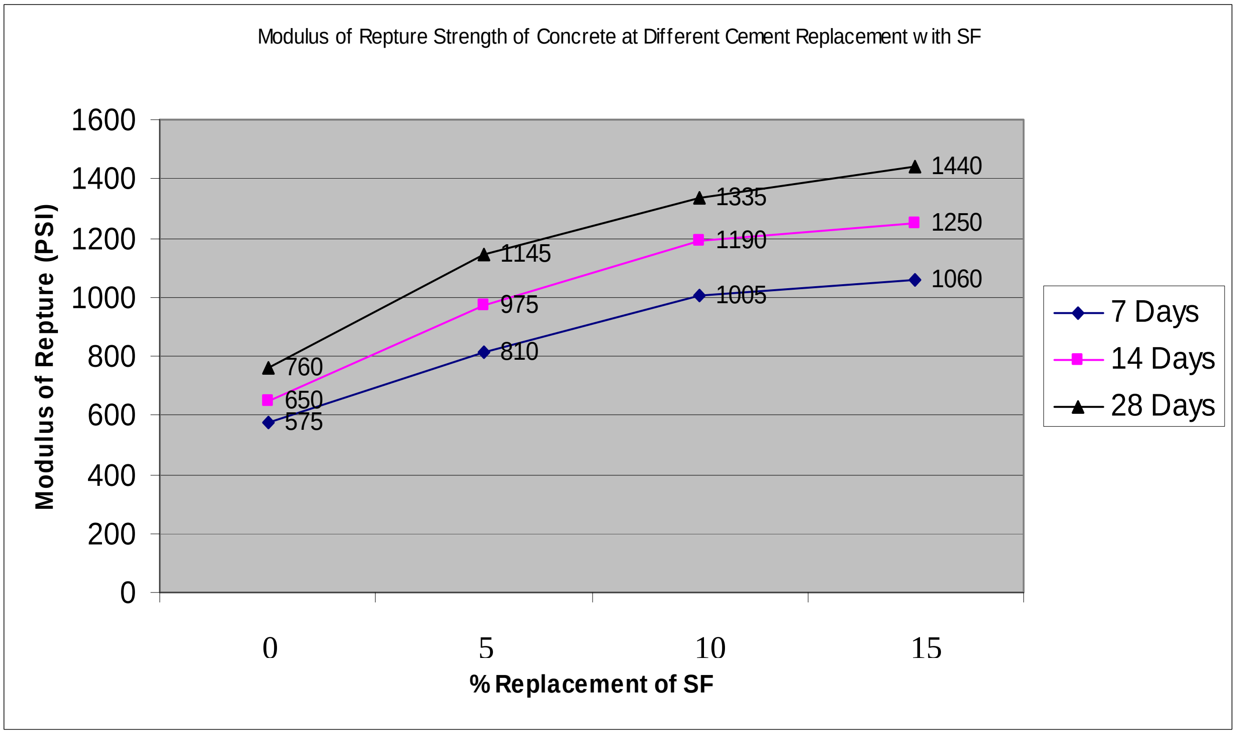

Fig 4.8 Modulus of Rupture (Sargodha)

Table 4.7 Summary of Test Results of Modulus of Rupture (Margala)

Ser	**% Replacement of SF**	**Crush**	**Modulus of Rupture (psi)**		
			7 Days	14 Days	28 Days
1.	0%	**Margala**	-	-	690
2.	5%		-	-	978
3.	10%		-	-	1030
4.	15%		-	-	1115

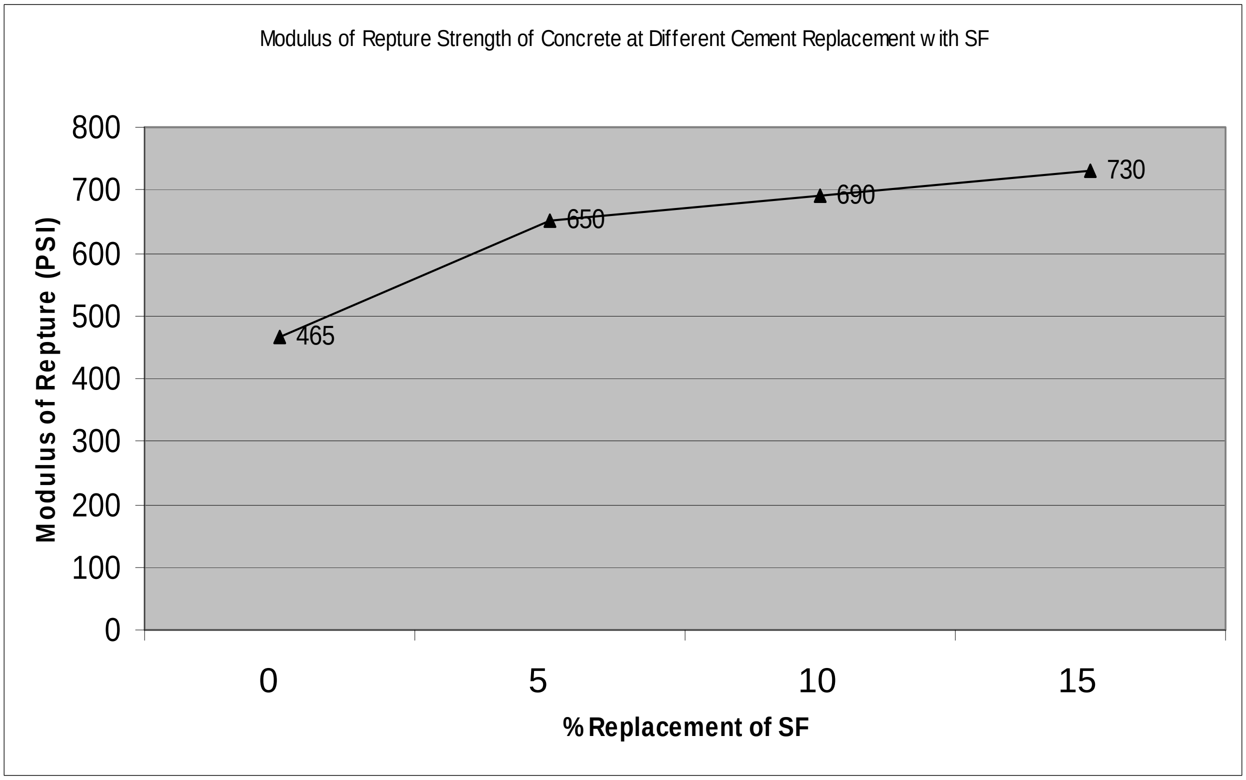

Fig 4.9 Modulus of Rupture (Margala)

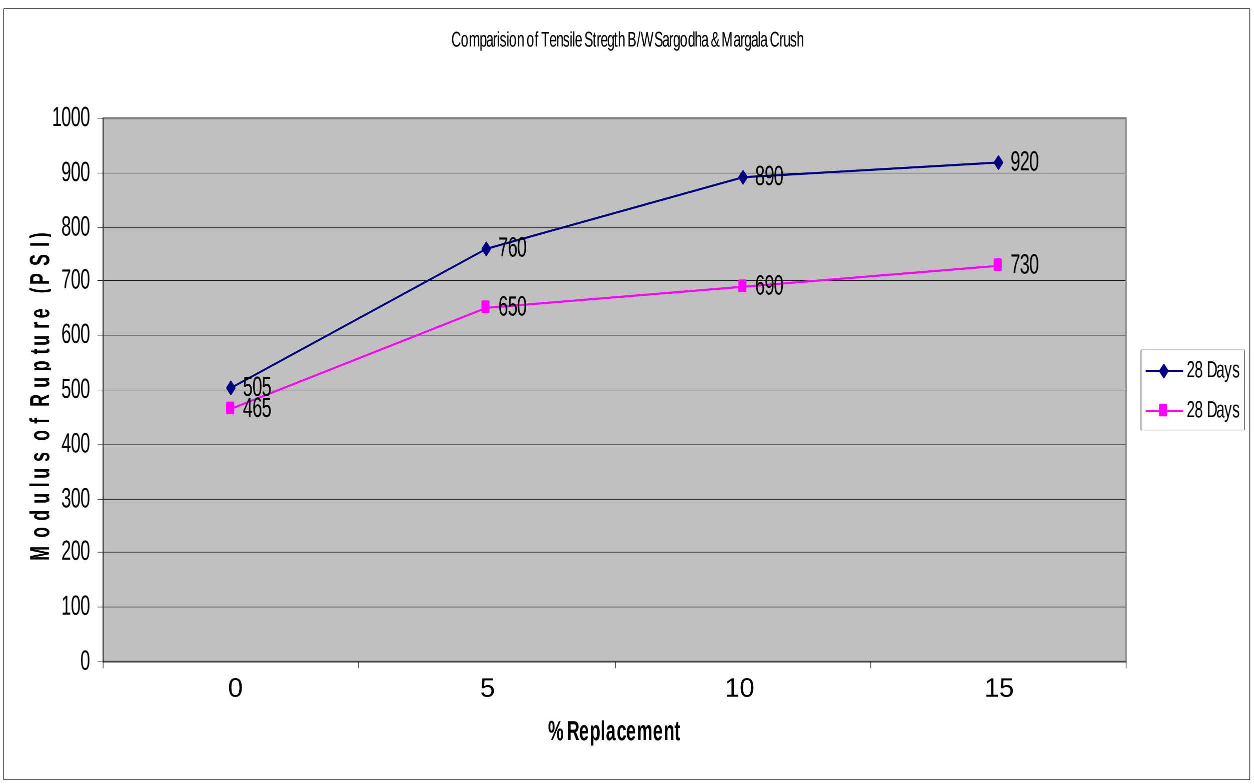

Fig 4.10 Comparison of Modulus of Rupture b/w Sargodha & Margala

- The increase in modulus of rupture of specimen is found to be proportional to the increase in percent replacement level.
- The mode of failure was brittle. The failure of beam was preceded by single major crack.
- The empirical equation to predict the modulus of rupture in terms of compressive strength as proposed by Walker and Bloem Is the same as proposed by Jerome which is given under:

$$f_r = 2.3 \times [f'_c]^{2/3} \text{(psi)}$$

Where, f_r and f'_c are modulus of rupture and compressive strength respectively.

- Based on this experimental study and the values obtained for K ranges from 2.4 to 2.5 as given below:-

$$\boxed{f_r = K \times [f'_c]^{2/3} \text{(psi)}}$$ Where, K ranges b/w 2.4 to 2.5

4.6 Modulus of Elasticity

Test results of the modulus of elasticity of concrete are summarized in table 4.8 & 4.9 and graphically represented in fig 4.11, 4.12 & 4.13. During the course of testing and from analysis of test results it is found that:

Table 4.8 Summary of Test Results of Modulus of Elasticity (Sargodha)

Ser	% Replacement of SF	Crush	Test Results EC (10^6)
1.	0%	Sargodha	3.8
2.	5%		3.91
3.	10%		4.1
4.	15%		4.3

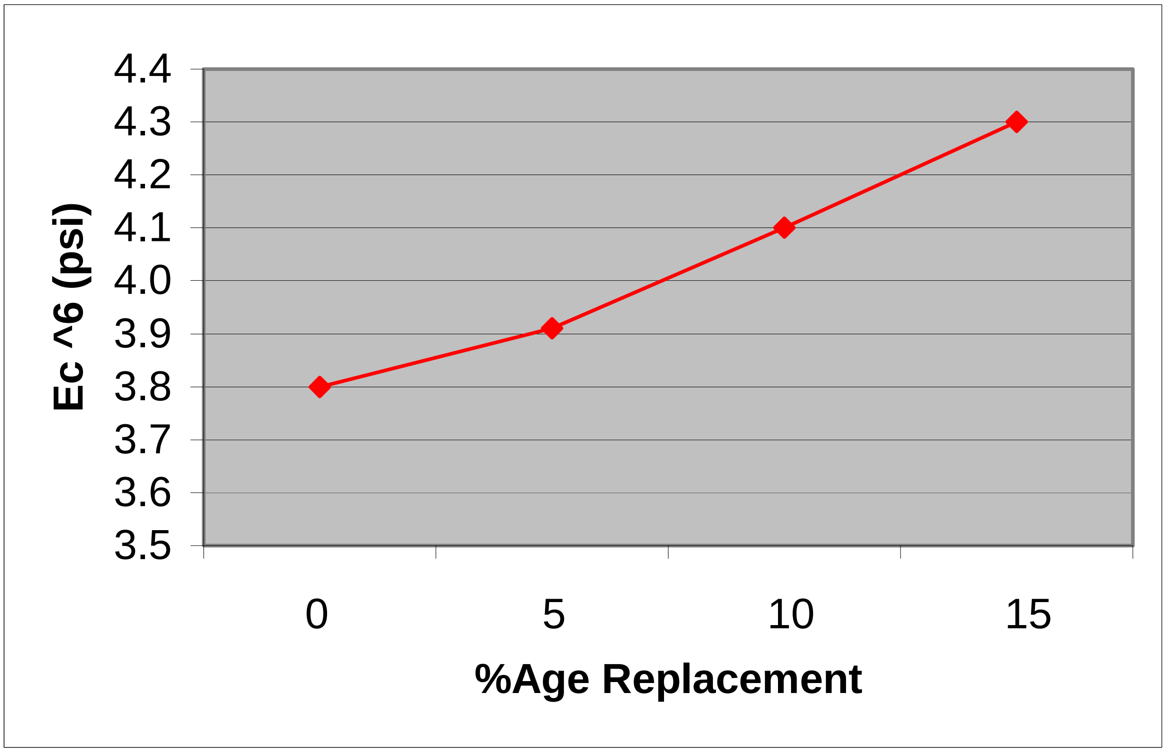

Fig 4.11 Modulus of Elasticity (Sargodha)

Table 4.9 Summary of Test Results of Modulus of Elasticity (Margala)

Ser	% Replacement of SF	Crush	Test Results EC (10^6)
1.	0%	Margala	3.6
2.	5%		3.85
3.	10%		3.99
4.	15%		4.15

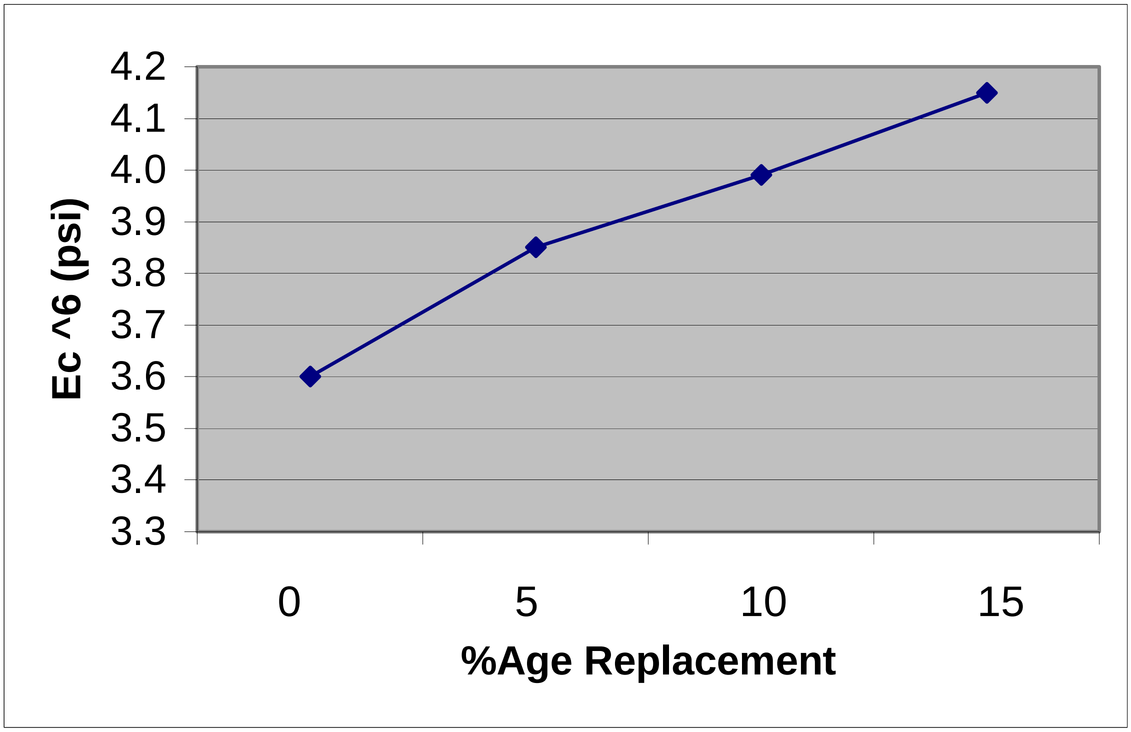

Fig 4.12 Modulus of Elasticity (Margala)

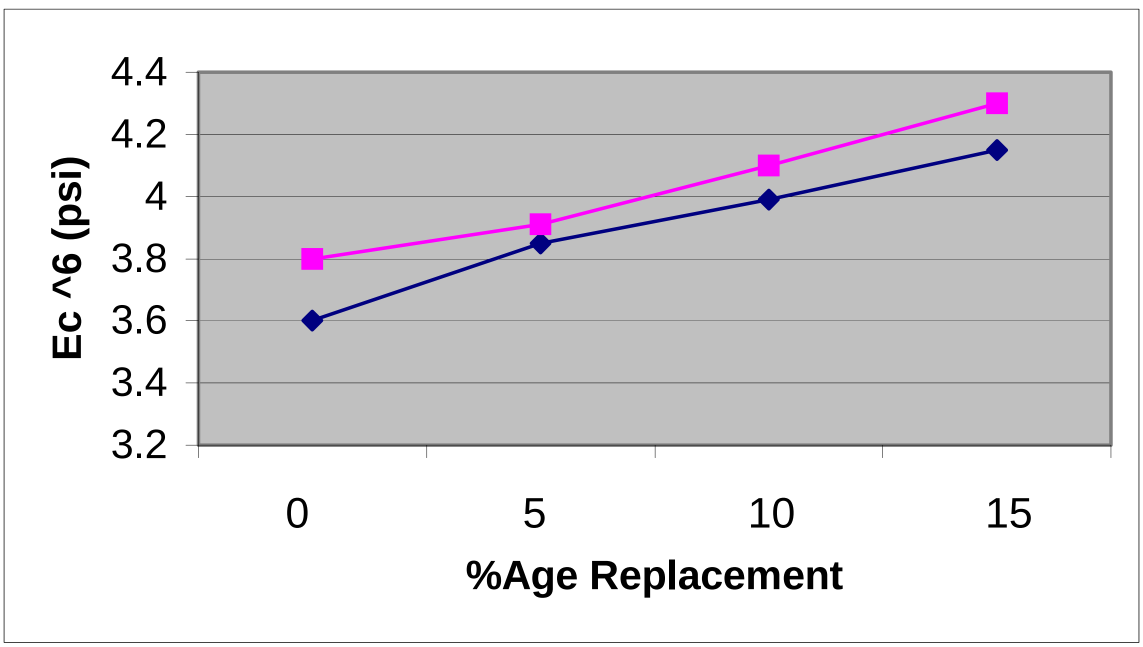

Fig 4.13 Comparison of Modulus of Elasticity b/w Sargodha & Maragla

- The increase in modulus of elasticity of specimen is found to be proportional to the increase in percent replacement level.

- From the test data it was observed that the concrete of higher compressive strength specially the one incorporating Sargodha crush showed higher values of modulus of elasticity confirming that the Sargodha crush is stronger than the margala. This also confirms that the concrete made with stronger aggregates has higher values of modulus of elasticity.

CHAPTER – V

CONCLUSIONS & RECOMMENDATIONS

5.1 CONCLUSIONS

High-Performance Concrete represents a rather recent development in concrete materials technology. Once the Pakistan industry recurmize the benefits of High-Performance Concrete its use will become much more widely accepted. The increased use and profitability of High-Performance Concrete will lead to better production facilities, design methods, curing and monitoring procedures all of which benefit humanity as a whole. The increased durability and strength of High-Performance Concrete are the most important factors which add credibility's for use in today's expanding world. After detailed investigations, the conclusions drawn are summarized below: -

- Mix proportions for the High-Performance Concrete are prepared by the same procedures as that for the normal strength concrete the only modification being the addition of Silica Fume and high range water reducers.
- The gradual decrease in the workability of concrete with increasing percent replacement of cement by silica fume, which was improved by addition of water reducers.
- Sticky effect observed during molding and handling of test specimens, but it does not hinder the molding process.
- An appreciable increase in compressive strength was noticed as the percent replacement of cement by silica fume increased.
- Rate of gain of compressive strength at early age, i.e. 7 days was higher as compare to one at later age.

- Once the replacement level of cement by silica fume increased from 10% to 15% it was found that gain in compressive strength is small, thus 10% partial replacement level is considered the "optimum".
- Sargodha crush gave higher compressive strength as compared to Margala.
- Brittle failure mode was observed accompanied by a burst.
- An appreciable increase in tensile strength was noticed as the percent replacement of cement by silica fume increased.

The splitting tensile strength did not follow the conventional relationship with the compressive strength. It was found to be towards higher side.

- An appreciable increase in flexural strength was noticed as the percent replacement of cement by silica fume increased.
- It is found that test results of modulus of elasticity of silica fume based concrete are higher than the one without silica fume.
- Sargodha crush gave higher modulus of elasticity as compared to Margala.
- High-Performance Concrete usage by construction industries can be guaranteed with additional local experience in design and construction, as well as quality assurance.

5.2 RECOMMENDATIONS

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

Topics of further research for scholars could be:-

- High strength concrete tends to be increasingly brittle. Research into the use of fiber as a secondary reinforcement in high performance concrete in order to improve ductility, bond with reinforcing bars and prestressing tendons, and other properties is strongly recommended.
- Since, durability is the fundamental property of high performance concrete, therefore, there is a need to undertake detailed study on durability of high performance concrete.
- The use of high performance concrete should be encouraged in special projects of high-rise buildings, long span bridges and off shore structures.

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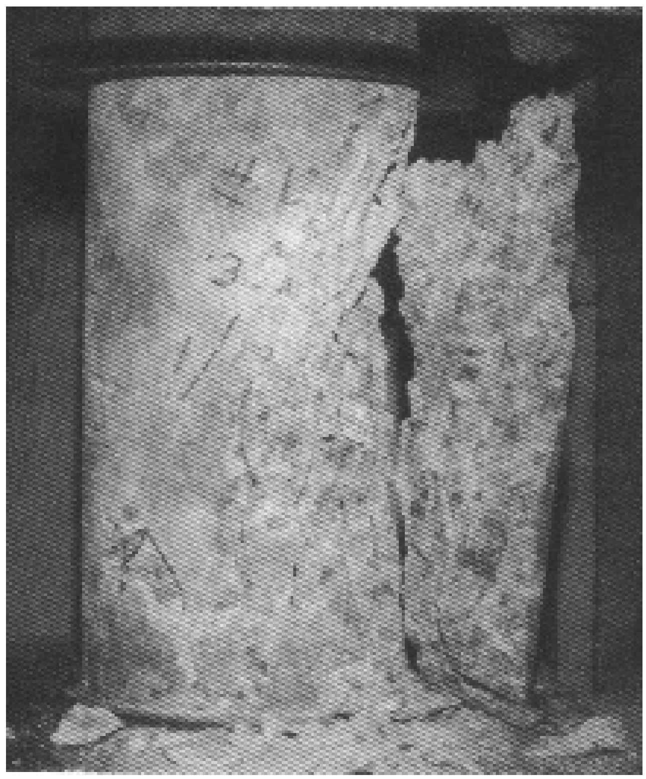
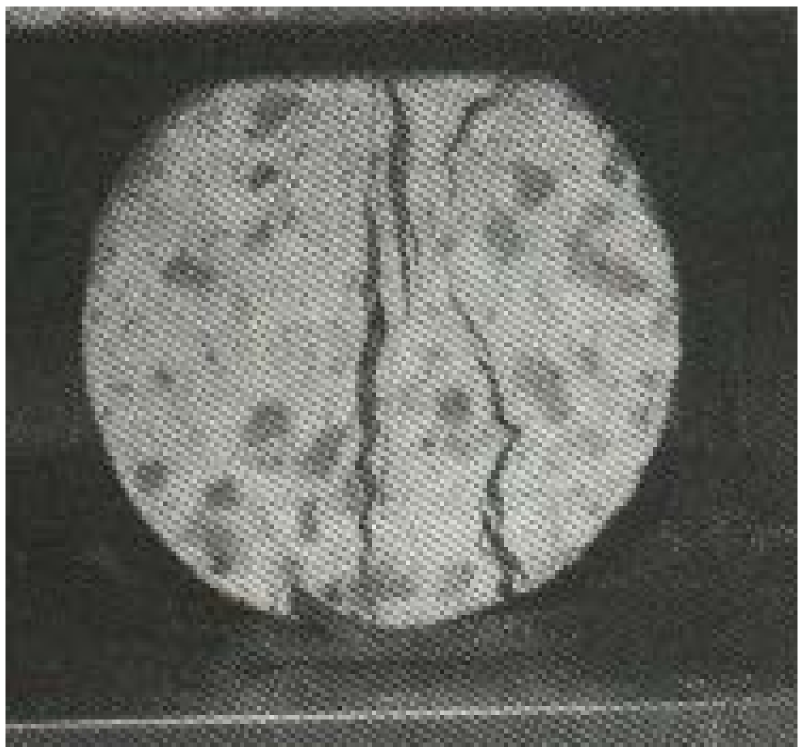
PHOTO SECTION

Compression Failure Without Silica fume

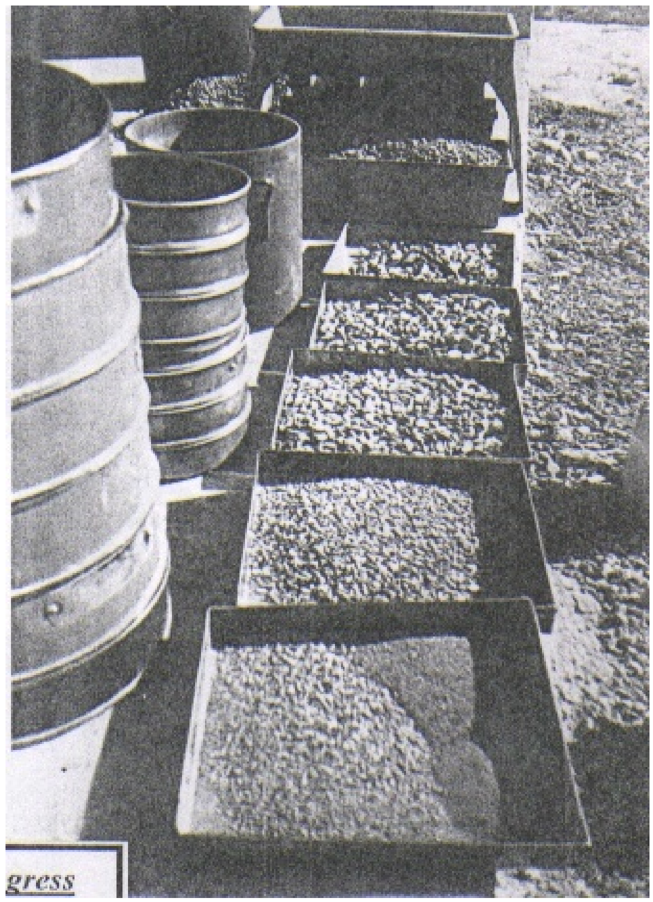


Compression Failure Containing 5 % SF

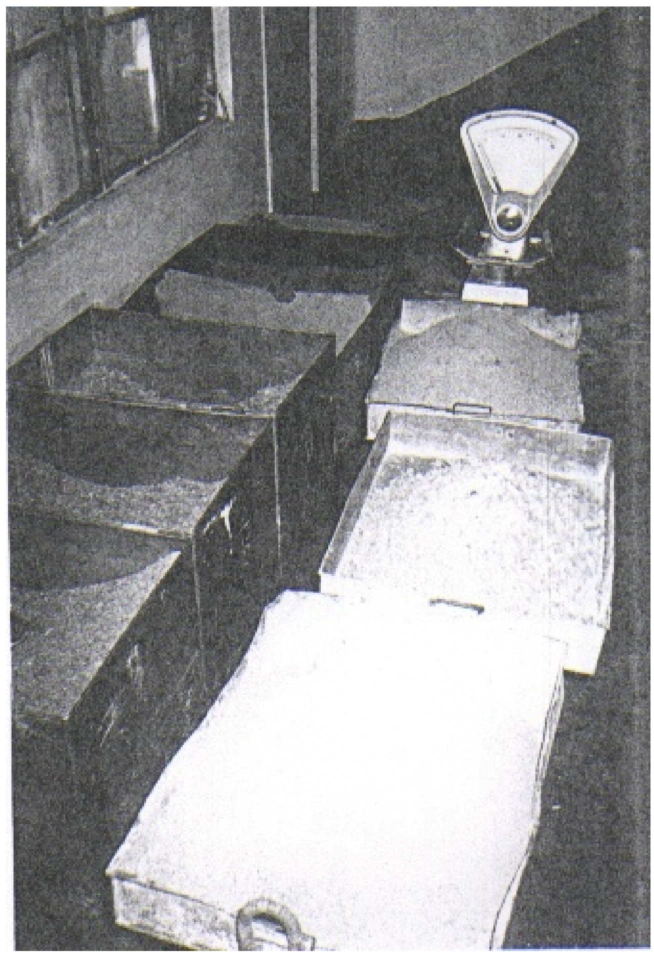
Compresion Failure Containing 10% SF



Tensile Failure View

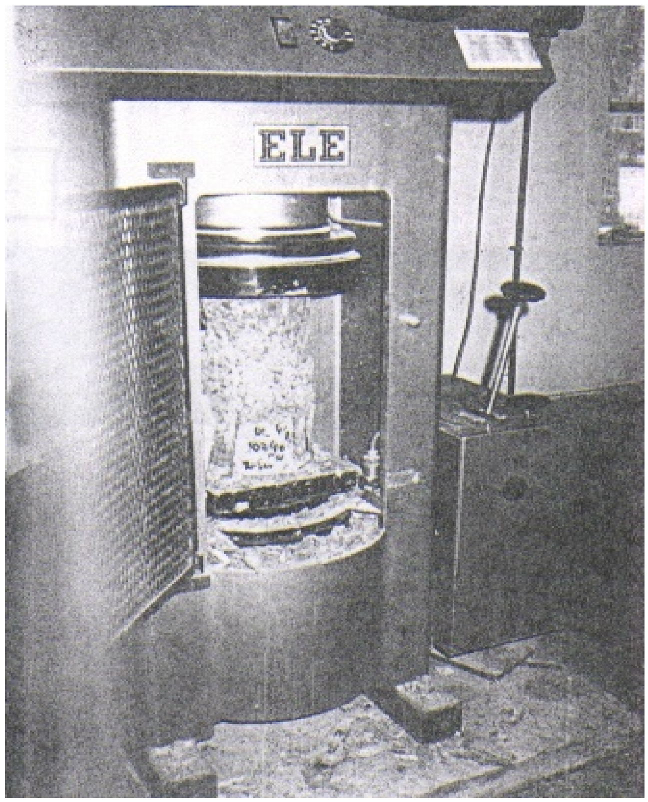


Sieving of Coarse Aggregate

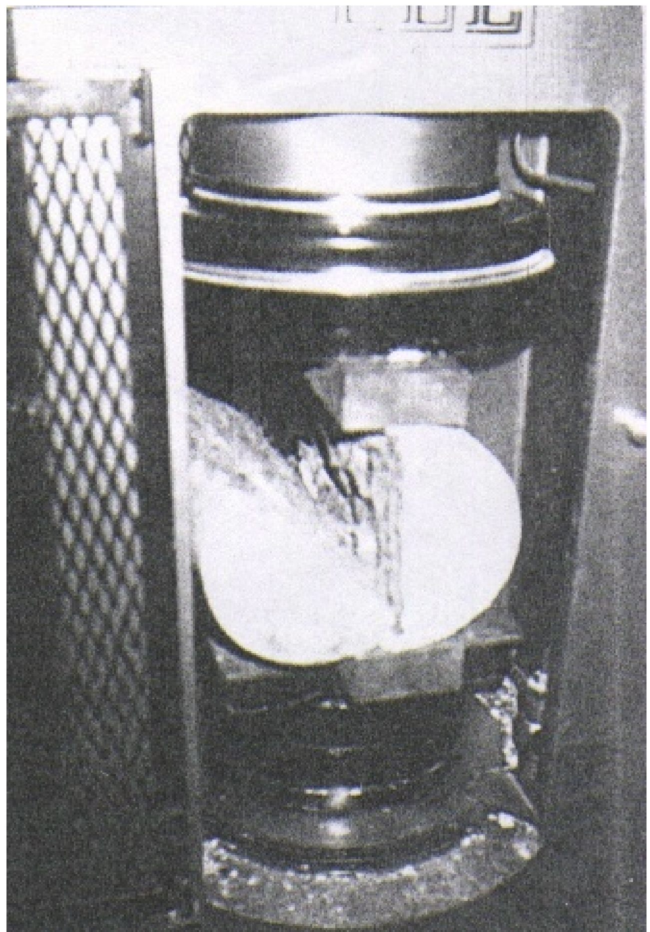


Weighing of Material to Prepare Batch

Capping in Progress



Compression Test in Progress



Tensile Testing in progress