CHAPTER ONE

INTRODUCTION

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1.1 General Introduction

Concrete is a composite material consisting of aggregates enclosed in a matrix of cement paste including possible pozzolans, has two major components, cement paste and aggregates. The strength of concrete depends upon the strength of these components, their deformation properties, and the adhesion between the paste and aggregate surface [1]. In recent years, the construction industry has shown significant interest in the use of high strength concrete (HSC), in applications such as dams, bridges and high rise buildings.

This is due to significant structural, economic and architectural advantages that HSC can provide compared to conventional, normal strength concrete (NSC).

Although high strength concrete is often considered a relatively new material, its developed has been gradual over many years. Definition of the minimum strength value for high – strength concrete varies with time and geographical location depending on the availability of raw material and the technical Know-how, and the demand form the industry [2].

Starting form a value of 34 MPa in the 1950s in the United States moving to upper values, the ACI 363, 1999 on high strength concrete defines a value of 51 MPa (cube strength) as a minimum value for high strength concrete. [3]

Production of HSC may or may not require special materials, but it definitely requires materials of highest quality and their optimum properties [4].

The production of HSC that consistently meets the requirements for workability and strength development places more stringent requirements on material selection than that for lower strength concrete (ACI 363R, 1999) [3].

However, many trial batches are often required to generate the data that enables the researchers and professionals to identify the optimum mix proportions for HSC [4].

High-strength concrete mix proportioning is a more critical process than the design of normal strength concrete mixtures. Usually, specially selected pozzolanic and chemical admixtures are employed, and the attainment of a low water-cementitious ratio is considered essential. Many trial batches are often required to generate the data that enables the researcher to identify optimum mix proportions. [3].

There is no “scientific” method for proportioning. This means that there is no chart that can be used to derive the mixture ingredients to meet specified level of performance. There are simply too many variables for such a chart to be developed. Here are some general rules for proportioning the purpose of this thesis was to study the potentiality and possibility of use Sudanese aggregate with supplementary cementations materials (silica fume) in high strength concrete mixes, and to study the effect of concrete ingredients on compressive strength, workability and cost of high strength concrete. It is also aimed to make a statistical modeling to predict compressive strength and workability of high strength concrete.

1.2 Significance of the Study

There are some parts of many major projects like dams, tall buildings and bridges were required high strength concrete, HSC, many applications of HSC have already been reported. Further growth on a much wider scale is anticipated in the near future because it offers cost efficient solutions to many structural design problems.

1.3 Objectives of the Study:

The main objective of this present investigation is to develop a mix design procedure for HSC To achieve this main objective the research has to go through different stages, within each stage there is specific objective would be achieved as stated below:

Objective (1):

first to prepare the Strength of concrete grade 60 MPa or grater with locally available material.

Objective (2):

To make a modeling to predicts concrete compressive strength and workability.

Objective (3):

To investigate the effects of various replacement levels of silica fume, with various Dosage of super plasticizer on compressive strength and concrete properties.

1.4 Research questions and hypothesis

It is hypothesized that, if silica fume and Super plasticizer with local aggregate were used in concrete and special techniques were used, then can we obtain high strength concrete, grade 60 MPa and above or not?

1.5 Problem Statements

The purpose of this research was to produce high strength concrete by using local Sudanese aggregate with supplementary cementations materials(silica fume) and to develop guidelines for optimum mix design methods for HSC from locally available aggregates in Sudan

1.6 Methodology of Research:

Stage (1):

Consulting References (books, papers, thesis, Research reports, ASTM standard British standard and ACI reports ……).

Stage (2):

Laboratory testing as follows:

- Testing of raw material (fine and coarse aggregate, cement) which include the following tests: sieve analysis, specific gravity, aggregate crushing value, aggregate impact value, absorption, Fineness, consistency,.
- Mix design grades of concrete (60MPa).
- Addition of Three percentages of Silica Fume (5, 10, and 15 % of cement content ..
- Testing of fresh and hardened concrete which include; consistency, initial setting time, final setting time, slump test, compressive strength,.

Stage (3):

analysis and discussion of results.

Stage (4):

Writing and preparation of thesis.

1.7 Research organization

This is contains five chapters:

Chapter one: includes a general introduction to research, Significance of the Study, Objectives of the Study, Statements of the problem and Methodology of Research.

Chapter two: covers the literature review.

Chapter three: Mix Design And Experimental Study.

Chapter four: presents and discusses the results of experiments.

Chapter five: covers the conclusion and proposes recommendations.

Chapter Two

Literature Review

2.1-Historical background

Although high-strength concrete is often considered a Relatively new material, its development has been gradual Over many years. As the development has continued, the Definition of high-strength concrete has changed. In the 1950s, concrete with a compressive strength of 5000 psi (34 MPa) was considered high strength. In the 1960s, concrete with 6000 and 7500 psi (41 and 52 MPa) compressive strengths were used commercially. In the early 1970s, 9000 psi (62 MPa) concrete was being produced. More recently, compressive strengths approaching 20,000 psi (138 MPa) have been used in cast-in-place buildings.

For many years, concrete with compressive strength in excess of 6000 psi (41 MPa) was available at only a few locations. However, in recent years, the applications of high-strength concrete have increased, and high-strength concrete has now been used in many parts of the world. The growth has been possible as a result of recent development in material technology and a demand for higher-strength concrete. The construction of Chicago’s Water Tower Place and 311 South Wicker Drive concrete buildings would not have been possible without the development of high-strength concrete. The use of concrete superstructures in long span cable-stayed bridges such as East Huntington, W.V., bridge over the Ohio River would not have taken place without the availability of high-strength concrete .[3]

2.2 General Definition of high-strength concrete

the definition of “high strength” was revised. Of course, there is no exact point of separation between “normal-strength” and “high-strength” concrete. According to the American Concrete Institute, high strength is defined as that over 6000psi (41 MPa) compressive strength.(4) This value was adopted by

ACI in 1984,but is not yet hard and fast ,because ACI recognizes that the definition of high strength varies on a geo graphical basis. Prof. J.Francis Young of the University of Illinois at Champaign-Urbana has developed a strength classification system that, though not yet adopted by a recognized authority ,Definition of the minimum strength value for high – strength concrete varies with time and geographical location depending on the availability of raw material and the technical Know-how, and the demand form the industry [2].

2.3 previous Studies on High-Strength Concrete

Defining “high strength” in terms of a universally applicable numerical value is not possible, at least not with any sound degree of rationale. “High strength” is a relative term that is dependent on many things, such as the quality of locally available concreting materials and construction practices.

High-strength concrete does not need to be defined in terms of one numerical value; however, at the end of this section, I present a range that most authorities might agree is a reasonable threshold for what would be considered “high-strength concrete,”.

Although high-strength concrete is often considered a relatively new material, its development has been gradual over many years.

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Whilst a number of studies have considered the development of a rational or standardized method of concrete mix design for HSC (de Larrard, 1999; Mehta and Aitcin, 1990), no widely accepted method is currently available. The main20 requirements for successful and practical HSC are a low water/cement ratio combined with high workability and good workability retention characteristics. In the absence of a standard mix design method, the importance of trial mixes in achieving the desired concrete performance is increased.

- The appropriate free water/cement ratio should be selected either from experience or by reference to published data. This will typically be in the range 0.25–0.30.
- The cement composition should be selected to maximize strength and other performance requirements. At its simplest this will be Portland cement blended with 5–10 per cent silica fume.
- Proportion coarse and fine aggregates to give a smooth overall grading curve in order to keep the water demand low. The proportion of fine aggregate is generally around 5 per cent lower (as a proportion of total aggregate) than for normal strength concrete. Care must be taken, however, not to make the mix too deficient in fine aggregate, particularly where the concrete is to be pumped.

- Use the saturation dosage of admixture (or admixtures), determined with a flow cone, to produce workability. It should be noted that most HSC is also high workability concrete, of, say, 600 mm flow table spread.

Trial mixes should be made and strength, workability and workability retention measured. Modifications can then be made to the mix to optimize the concrete's performance.

The production of HSC that consistently meets the requirements for workability and strength development places more stringent requirements on material selection than that for lower strength concrete (ACI 363R, 1999) required to generate the data that enables the researcher professionals to identify the optimum mix proportions

HSC [3].

2.4 previous Studies on High-Strength Concrete In Sudan:

production and characterization of high strength concrete (HSC) for heightening of an existing concrete dam in the middle of Sudan. Hundreds of trial mixes were performed and tested using local Sudanese aggregates with addition of mineral admixtures (Silica Fume and Fly Ash) and Super plasticizers. Six grades of HSC (50, 60, 70, 80, 90, 100 MPa) had been success fully produced and their mechanical properties were measured and documented. Statistical analysis of tests results was performed and

simple correlations were developed relating compressive strength to flexural and Splitting Strengths. The results have offered an important insight for optimizing the rheological characteristics of HSC and permitted to develop guidelines for optimum mix design methods for HSC from locally available aggregates in Sudan. The effect of w/c ratio on strength of HSC was also highlighted. It is concluded that local concrete materials, in combination with mineral admixtures can be utilized in producing High Strength Concrete in Sudan.

2.5 High Strength Concrete Materials

2.5.1 Cements:

The choice of Portland cement for high-strength concrete is the objective, such as in prestressed concrete, there is no need to use a Type III cement. Furthermore, within a given cement type, different brands will have different strength development characteristics because of the variations in compound composition and fineness that are permitted by ASTM C 150.Initially, silo test certificates should be obtained from potential suppliers for the previous 6 to 12 months. Not only will this give an indication of strength characteristics from the ASTM C 109 mortar cube test, but also, more importantly, it will provide an indication of cement uniformity. The cement supplier should be required to report uniformity in accordance with ASTM C 917.

If the tricalcium silicate content varies by more than 4 percent, the ignition loss by more than 0.5 percent, or the fineness by more than 375 cm2/g (Blaine), then problems in maintaining a uniform high strength may result.2.1Sulfate (SO,) levels should be maintained at optimum with variations limited to ± 0.20 percent.

Although mortar cube tests can give a good indication of potential strength, tests should be run on trial batches. These should contain the materials to be used in the job and be prepared at the proposed slump, with strengths determined at 7, 28, and 56days.

The effect of cement characteristics on water demand is more noticeable in high-strength concretes because of the High cement contents can be expected to result in a I high temperature rise within the concrete.

2.5.2-Aggregates

General - Both fine and coarse aggregates used for high-strength concrete should, as a minimum, meet the requirements of ASTM C 33

2.5.2.1 Fine aggregate

Fine aggregates with a rounded particle shape and smooth texture have been found to require less mixing water in concrete and for this reason are preferable in high-strength concrete.

The optimum gradation of fine aggregate for high strength Concrete is determined more by its effect on Water requirement than on physical packing. One report2.10 Stated that a sand with a fineness modulus (PM) Below 2.5 gave the concrete a sticky consistency, making it difficult to compact.Sand with an FM of about 3.0 gave the best workability and compressive strength. High-strength concretes typically contain such high Contents of fine cementations materials that the grading of the aggregates used is relatively unimportant compared to conventional concrete.

2.5.2.2 Coarse aggregate

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 in. (12.7 mm) or H in. (9.5 mm). Maximum sixes of ¾ in. (19.0 mm) and 1 in. (25.4 mm also have been used successfully. Smaller aggregate sixes are also considered to produce higher concrete strengths because of less severe concentrations of stress around the particles, which are caused by differences between the elastic modulus of the paste and the aggregate. Many studies have shown that crushed stone produces higher strengths than rounded gravel

2.5.3-Water

The requirements for water quality for high-strength concrete are no more stringent than those for conventional concrete.

Usually, water for concrete is specified to be of potable quality. This is certainly conservative but usually does not constitute a problem since most concrete is produced near a municipal water supply

2.5.4-Mineral admixtures and slag cement

Finely divided mineral admixtures, consisting mainly of fly ash and silica fume, and slag cement have been widely used in high-strength concrete.

2.5.5.1 Fly ash

Fly ash for high-strength concrete is classified into two classes. Class F fly ash is normally produced from burning anthracite or bituminous coal and has pozzolanic properties, but little or no cementations properties.

Class C fly ash is normally produced from burning lignite or sub bituminous coal, and in addition to having pozzolanic properties, has some autogenously cementitious properties. In general, Class F fly ash is available in the eastern United States and Canada, and Class C fly ash is available in the western United States and Canada.

Specifications for fly ash are covered in ASTM C 618.

Methods for sampling and testing are found in ASTM C 311. Variations in physical or chemical properties of mineral admixtures, although within the tolerances of these specifications, may cause appreciable variations in properties of high-strength concrete.

Such variations can be minimized by appropriate testing of shipments and increasing the frequency of sampling.

It is extremely important that mineral admixtures be tested for acceptance and uniformity and carefully investigated for strength-producing properties and compatibility with the other materials in the high-strength concrete mixture before they are used in the work.

*2.5.5.2 **Silica fume** –*

Silica Fume is a by-product of the smelting process in the production of silicon metal and ferrosilicon alloys. It has also been called silica fume, micro silica, amorphous silica and other similar names. However, the silica fume used in concrete are those from the production process of silicon metal or ferrosilicon alloy containing more than 75% silicon [5]. Figure (2.1) shows a typical silica fume as it appears after being collected from a furnace.

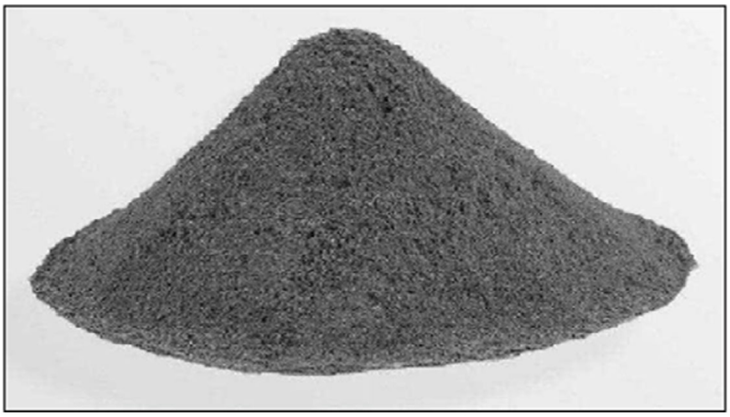

Figure (2.1) As-produced silica fume. This is what the material looks like after it is collected.

In general, they have:

i) SiO_2 contents ranging from 85 to 96%.

ii) Amorphous structures.

Silica fume may be obtained in its powder form, densified, or in slurry form mixed with 50% water by weight. Its specific gravity is about 2.20, but its bulk density is only 200 to 300 kg per cubic meter. The specific surface area ranges from 15,000 to 30,000 sq. m per kg (*Silica Fume User Manual, SFA 2005).*

Due to extreme fineness and high silica content, silica fume is a highly effective pozzolanic material. Silica Fume is used in concrete to improve its properties. It has been found that silica fume improves compressive strength, bond strength, and abrasion resistance, reduces permeability, and therefore helps in protecting reinforcing steel from corrosion.

Pozzolanic reaction between and calcium hydroxide released by hydration of Portland cement leads to the formation of C-S-H gel. It is a very reactive pozzolan. Although the nature of the hydration products of and its influence on cement hydration are not fully understood at present, the effect is a refinement of the pore structure when is added to the cementitious system.[6]

This leads to a reduction in permeability and hence the enhancement of the mechanical properties and durability of concrete containing silica fume.

The Chemical properties of silica fume and Physical properties are shown in Table (2.1), Table (2.2),below respectively

Table (2-1) The Chemical properties of silica fume:

Amorphous
Silica dioxide > 85%
Trace elements depending upon type of fume

Table (2-2) The Physical properties of silica fume:

Particle size (typical) < 1 µ m
Bulk density : (As production): 130 to 340 kg /$m^{3.}$ (Densified): 480 to 720 kg /$m^{3.}$
Specific gravity 2.2
Specific surface 15,000 to 30,000 m^2/kg

Table (2-3) Comparison of Chemical and Physical Characteristics Silica Fume and Cement

Properties	**Portland cement**	**Silica fume**
SiO_2 Content %	21	85 – 97
Al_2O_3 content %	5	-
Fe_2O_3 content %	3	-
CaO content %	62	< 1
Fineness as surface area m^2/kg	370	15,000 – 30,000
Specific gravity	3.15	2.2
General use in concrete	Primary binder	Property enhancer

There are two main methods of using silica fume in concrete:

(i) As a partial replacement of cement to obtain reduction in cement content but not economical in the local context.

(ii) As an addition to improve concrete properties for both fresh and hardened concrete.

Silica fume has been used as an addition to concrete up to 15 percent by weight of cement, although the normal proportion is 7 to 10 percent. With an addition of 15 percent, the potential exists for very strong and brittle concrete. It Increases the water demand in a concrete mix, however, dosage rates of less than 5 percent will not typically require a water reducer. High replacement rates will require the use of a high range water reducer [7]. Concrete incorporating more than 10% silica fume becomes sticky, in order to enhance workability, the initial slump should be increased. It has been found that silica fume reduces bleeding because of its effect on rheological properties [4].

- **Effects Of Silica Fume On Properties Of Fresh Concrete:**

- **Water demand**

The water demand of concrete containing silica fume increases with increasing amounts of silica fume (Scali,Chin, and Berke 1987; Carette and Malhotra 1983a). This increase is due primarily to the high surface area of the silica fume. In order to achieve a maximum improvement in strength and permeability, silica-fume concrete should generally be made with a water-reducing admixture, a high-range water-reducing admixture (HRWRA), or both.

- **Workability**

Fresh concrete containing silica fume is more cohesive and less prone to segregation than concrete without silica fume. As the silica-fume content is increased, the concrete may appear to become sticky. To maintain the same apparent workability, industry experience has shown that it is necessary to increase the initial slump of the concrete with silica fume by about 2 in. (50 mm) (Jahren 1983) above that required for conventional portland-cement concretes.

- **Slump loss**

The presence of silica fume by itself will not significantly change the rate of slump loss of a given concrete mixture. However, since silica fume is typically used in conjunction with water-reducing admixtures, or HRWRA, or both, there may be a change in slump-loss characteristics which is actually caused by the chemical admixtures selected .Different chemical admixtures produce differing rates of slump loss.

- **Time of setting**

Silica-fume concrete usually includes chemical admixtures that may affect the time of setting of the concrete. Experience indicates that the time of setting is not significantly affected by the use of silica fume by itself. Practical control of the time of setting may be achieved by using appropriate chemical admixtures.

- **Segregation**

Concrete containing silica fume normally does not segregate appreciably because of the fineness of the silica fume and the use of HRWRA. Segregation may occur in many types of concrete (with and without silica fume) with excessive slump, improper proportioning, improper handling, or prolonged vibration. The use of silica fume will not overcome poor handling or consolidation practices.

- **Bleeding and plastic shrinkage**

Concrete containing silica fume shows significantly reduced bleeding. This effect is caused primarily by the high surface area of the silica fume to be wetted; there is very little free water left in the mixture for bleeding (Grutzeck, Roy, and Wolfe-Confer 1982). Additionally, the silica fume reduces bleeding by physically blocking the pores in the fresh concrete. Plastic shrinkage cracks generally occur when the water evaporation rate from the concrete surface exceeds the rate at which water appears at the surface due to bleeding, or when water is lost into the sub grade.

- **Color of concrete**

Fresh and hardened concretes containing silica fume are generally darker than conventional concrete.

- **Air entrainment**

The dosage of air-entraining admixture to produce a required volume of air in concrete usually increases with increasing amounts of silica fume due to the very high surface area of silica fume and to the effect of carbon when the latter is present (Carette and Malhotra 1983a).

- **Unit weight (mass) of fresh concrete**

The use of silica fume will not significantly change the unit weight of concrete. Any changes in unit weight are the result of other changes in concrete proportions madeto accommodate the use of the silica fume. [23]

- **Effects Of Silica Fume On Properties Of Hardened Concrete:**
- ***Porosity*—**

. Tazawa and Yonekura (1986) reported that under the same drying conditions, water will evaporate more rapidly from large pores than small pores.The slower evaporation rate from paste and concrete containing
silica fume is due to their having a larger proportion of fine pores than do conventional paste and concrete.

- ***Permeability***-The permeability of concrete is determined by the measurement of the liquid or vapor flow rate through the medium. the permeability to liquids and vapors is reduced by silica fume addition. High concrete permeability is closely linked to poor durability. [23]

- **compressive strength:**

It is well recognized that silica fume can contribute significantly to the compressive strength development of concrete. This is because of the filler effect and the excellent pozzolanic properties of the material, which translate into a stronger transition zone at the paste–aggregate interface. The extent to which silica fume contributes to the development of compressive strength depends on various factors, such as the percentage of silica fume, the water/cement plus silica fume ratio, cementations materials content, cement composition, type and dosage of super plasticizer, temperature, curing conditions, and age.

Super plasticizing admixtures play an important role in ensuring optimum strength development of silica-fume concrete. The water demand of silica-fume concrete is directly proportional to the amount of silica fume (used as a percentage replacement for Portland cement) if the slump of concrete is to be kept constant by increasing the water content rather than by using a super plasticizer. In such instances, the increase in the strength of silica-fume concrete over that of control concrete is largely offset by the higher water demand, especially for high silica-fume content at early ages. In general, the use of super plasticizer is a prerequisite to achieving proper dispersion of the silica fume in concrete and fully utilizing the strength potential of the fume. In fact, many important applications of silica fume in concrete depend strictly upon its utilization in conjunction with super plasticizing admixtures. Silica-fume concretes have compressive strength development patterns that are generally different from those of Portland cement concretes. The strength development characteristics of these concretes are somewhat similar to those of fly-ash concrete, except that the results of the pozzolanic reactions of the former are evident at earlier ages.

This is due to the fact that silica fume is a very fine material with a very high amorphous silica content. The main contribution of silica fume to concrete strength development at normal temperatures takes place between the ages of about 3 and 28 days. The overall strength development patterns can vary according to concrete proportions and composition and are also affected by the curing conditions.

Curing temperatures have also been shown to affect significantly the strength development of silica fume concrete. This aspect has been examined in some detail by several investigators in Scandinavia. In general, these investigations have indicated that the pozzolanic reaction of silica fume is very sensitive to temperature, and elevated-temperature curing has a greater strength-accelerating effect on silica-fume concrete than on comparable Portland cement concrete.

The dosage of silica fume is obviously an important parameter influencing the compressive strength of silica-fume concrete. For general construction, the optimum dosage generally varies between 7 and 10%; however, in specialized situations, up to 15% silica fume has been incorporated successfully in concrete [8]. Fig (2-2) below show the effect of silica fume (SF) to compressive strength Where C-type : is the sign specimens different dosage rate

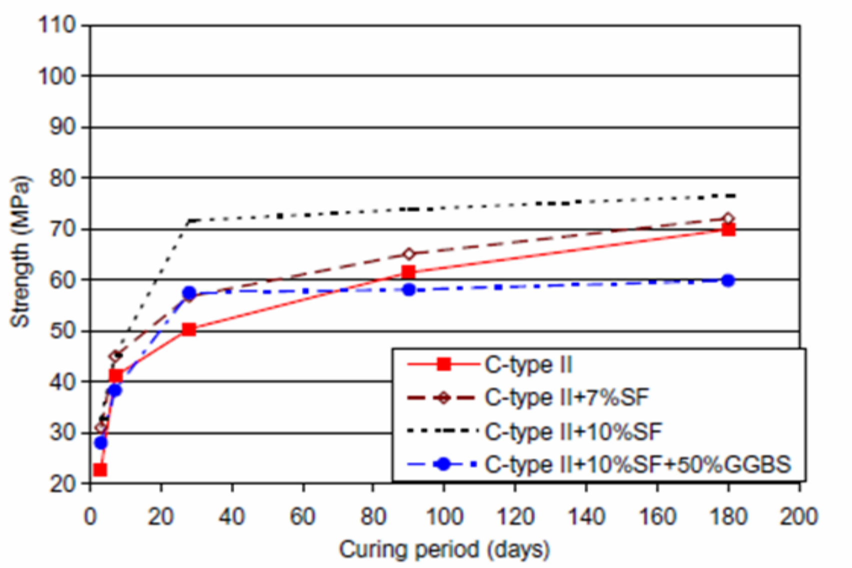

Fig (2-2) the effect of silica fume (SF) to compressive strength

Where C-type : is the sign specimens different dosage rate

At a water/cement + silica fume ratio of 0.21 and 500 kg/m3 cement and 40 kg/m3 silica fume, the chloride-ion penetration was found to be 196 coulombs at 28 days, compared to 1246 C for the reference concrete. This reduction is primarily due to the refined pore structure and increased density of the matrix [9].

When silica fume is added to concrete, it reacts and tends to close the capillary pores reducing the carbonation effect, according to the reaction:

$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$.

The improvement in the carbonation resistance, optimum compacting of the concrete and greater water proofness obtained with the use of silica fume, will depend directly on the water/cement ratio used.

According to the different authors, there are various factors that influence carbonation speed: type of cement, environmental conditions, water cement ratio and microstructure of concrete.

In addition to these factors the influence of combination of silica fume with water reducing admixtures of diverse chemical nature. Generally, and due to the reduction in the w/c ratio, the porosity of cement paste and hence the permeability of the corresponding concrete are reduced [10]. Fig (2-3) below show the effect of silica fume (SF) to permeability Where P-type : is the sign specimens different dosage rate.

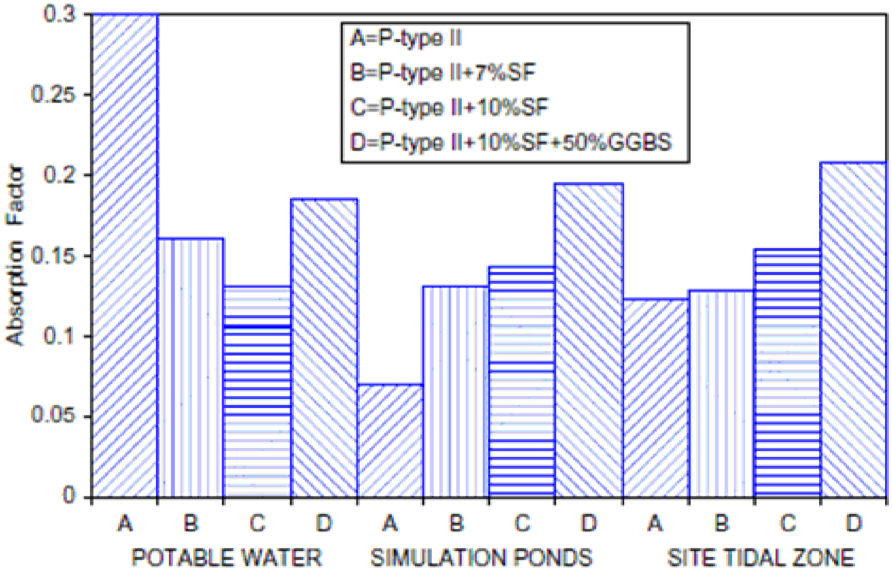

Fig (2-3) the effect of silica fume (SF) to permeability

Where P-type : is the sign specimens different dosage rate

- **Proportioning Silica-fume Concrete Basic Considerations**

Following are several basic considerations to keep in mind when proportioning silica-fume concrete:

Work to a fixed cementitious materials content and a fixed water to cementitious material ratio (w/cm.) In many cases with conventional concrete with a low specified w/cm, the cement content is raised to bring in additional water to provide slump. This practice is usually not the case for silica-fume concrete because it will result in very high contents of cementations materials. Both the total amount of cementations material sand the maximum water content will frequently be specified. Will there be enough water to hydrate the cement? This question is frequently asked. Don't worry about whether there is enough water. [7].

Concrete mixtures with w/cm of less than 0.25 have achieved over 120 MPa compressive strength. If the cement is not hydrated, it will serve as filler material to fill in void spaces in the mixture.

Don't be particularly concerned with the slump resulting from water alone("water slump" or "initial slump".) Because silica-fume concrete mixtures usually contain so little water, there may not be enough water to develop a measurable slump until after the chemical admixtures are added.

Some specifies are uncomfortable about using a super-plasticizer without first verifying a water slump of 50 to 75 mm. This requirement is still seen in many specifications. For many high-performance concrete applications, the w/cm will be so low that there is not enough water to get a measurable slump and still develop a concrete with the desired performance characteristics.

Use chemical admixtures to achieve adequate slump for placement.

Usually, both a water-reducer (normal setting or retarding) and a super plasticizer will be used.

The water-reducer is frequently added early in the mixing sequence to help loosen up the concrete and the super plasticizer is added later to bring the concrete to the desired slump for transportation and placement. In some cases it may be necessary to go above manufacturer's recommended limits for chemical admixture dosages, particularly for super-plasticizers.

For high-strength concrete with a very low w/cm, the necessary dose may be as much as twice there commended dose. In most cases such high dosages will retard the concrete; however, once the concrete begins to set, it will gain strength very rapidly.

Testing at the high dose of admixture is recommended to ensure that other properties such as air content are not being affected. Entrained air is required with silica-fume concrete if it will be exposed to freezing and thawing while saturated.

- **Construction Considerations**

Once the project requirements are identified, it is critical to determine the requirements of the contractor who will actually be placing the concrete. Here are a few topics to consider:

Slump: Silica-fume concrete is very cohesive and behaves somewhat differently than conventional concrete. A given slump will not be the same workability for concrete with and without silica fume.

Usually, the slump for the silica-fume concrete should be increased by about 40 to 50 mm over concrete without silica fume to achieve the same workability.

Maximum slump: A good rule of thumb for silica-fume concrete is to place it at as high a slump as possible for the placement. Using a higher slump will make closing the surface and achieving the desired finish much easier. Frequently, for bridge decks or parking structure flatwork, the slump will be determined by the slope of the structure. Place at the highest slump that will hold on the slope. [7].

- **Proportioning Procedure**

Proportions for silica-fume concrete are typically developed to meet specific project requirements. These requirements may be prescriptive in nature giving details about the mixture proportions or they may be purely performance giving only the requirements that must be met. In either case, it is best to follow a step-by-step procedure to develop the mixture proportions for a specific project. [7].

- **General Rules**

There is no "scientific" method for proportioning. This means that there is no chart that can be used to derive the mixture ingredients to meet a specified level of performance. There are simply too many variables for such a chart to be developed. Here are some general rules for proportioning:

Test at both the laboratory and production scale during mixture development. The process is too complex to predict what the outcome will be without appropriate testing. Allow plenty of time for the necessary testing.

Finally, follow the procedure described in the following section.

This procedure has evolved over many years and is the best recommendation currently available.

- **Step-By-Step Procedure**

This section presents a seven step procedure.

STEP 1**.** Determine project requirements. Read the specifications carefully.

STEP 2. Incorporate local aggregates into the starting mixture.

STEP 3. Prepare laboratory trial mixtures.

STEP 7. Conduct production-scale testing.

to confirm the performance of a particular concrete mixture. [7].

2.4.4.3 Ground Granulated Blast-furnace Slag (GGBS):

Ground granulated blast-furnace slag (GGBS) is a by-product in the manufacture of pig iron and the amounts of iron and slag obtained of the same order. The slag is a mixture of lime, silica and alumina, the same oxides that make up Portland cement, but not in the same proportion. The composition of blast-furnace slag is determined by that of the ores, fluxing stone and impurities in the coke charged in to the blast furnace. Typically, silica, calcium, aluminum, magnesium and oxygen constitute 95% or more of the blast- furnace slag. To maximize hydraulic (cementations) properties, the molten slag must be chilled rapidly as it leaves the blast furnace. Rapid quenching or chilling minimizes crystallization and converts the molten slag into fine-aggregate-size particles generally smaller than a 4.75 mm (No 4) sieve, composed predominantly of glass. This product is referred to as granulated iron blast- furnace slag (GGBS) is obtained by finely grinding of this material.

The hydration of the Portland cement results from the production of portlandite crystal [Ca(OH)2] and amorphous calcium silica hydrate get [C3S2H3](C–S–H) in large amounts. hydrated cement paste involves approximately 70% C–S–H, 20% Ca(OH)2; 7% sulpho- aluminates and 3% secondary phases .The [Ca(OH)2] which appears as the result of the chemical reactions affect the quality of the concrete adversely by forming cavities as it is partly soluble in water and lacks enough strength . The use of ground granulated blast-furnace slag (GGBS) has a positive effect on binding the [Ca $(OH)_2$] compound , which decreases the quality of the concrete.

The cementitious and pozzolanic behavior of ground granulated blast-furnace slag (GGBS) is essentially similar to that of high- calcium fly ash. At 40% and 50% cement replacement by weight [25].

A number of authors have studied the influence of GGBS addition on the properties of OPC mortars and concrete concluding that GGBS enhances the general performance of PC composites improving workability, reducing creep and drying shrinkage, raising the ultimate compressive strength and reducing bleeding and heat of hydration.

The GGBS enhances concrete workability due to its surface properties and fineness (approximately 460 Blaine (m2/kg.min)). According to this author, this makes GGBS 2-3 times finer than Portland cement, leading to an enhanced workability and a better performance in bleeding and setting times.

- **Ground Granulated Blast furnace Slag (GGBS) properties:**

Ground granulated blast furnace slag (GGBS) hardens very slowly and, for use in concrete, it needs to be activated by combining it with Portland cement. A typical combination is 50 per cent GGBS with 50 per cent Portland cement, but percentages of GGBS anywhere between 20 and 80 per cent are commonly used. The greater the percentage of GGBS, the greater will be the effect on concrete Properties. The setting time of concrete is influenced by many factors, in particular temperature and water/cement ratio. With GGBS, the setting time will be extended slightly, perhaps by about 30 minutes. The effect will be more pronounced at high levels of GGBS and/or low temperatures. An extended setting time is advantageous in that the concrete will remain workable longer

- **Effect of (GGBS) to compressive strength:**

With the same content of cementitious material (the total weight of Portland cement plus GGBS), similar 28-day strengths to Portland cement will normally be achieved when using up to 50 per cent GGBS. At higher GGBS percentages the cementitious content may need to be increased to achieve equivalent 28-day strength. GGBS concrete gains strength more steadily than equivalent concrete made with Portland cement. For the same 28-day strength, a GGBS concrete will have lower strength at early ages but its long-term strength will be greater. The reduction in early-strength will be most noticeable at high GGBS levels and low temperatures. Typically a Portland cement concrete will achieve about 75 per cent of its 28-day strength at seven days, with a small increase of five to 10 per cent between 28 and 90 days. By comparison, a 50 per cent GGBS concrete will typically achieve about 45 to 55 per cent of its 28-day strength at seven days, with a gain of between 10 and 20 per cent from 28 to 90 days. At 70 per cent GGBS, the seven-day strength would be typically around 40 to 50 per cent of the 28-day strength, with a continued strength gain of 15 to 30 per cent from 28 to 90 days. Under normal circumstances, the striking times for concretes containing up to 50% GGBS, do not increase sufficiently to significantly affect the construction programme. However, concretes with higher levels of GGBS will not always achieve sufficient strength after one day to allow removal of vertical formwork, particularly at lower temperatures, lower cementitious contents and in thinner sections [26].

2-4.5 Chemical admixtures:

Chemical admixtures are the ingredients in concrete other than Portland cement, water, and aggregate that are added to the mix immediately before or during mixing. Producers use admixtures primarily to reduce the cost of concrete construction; to modify the properties of hardened concrete; to ensure the quality of concrete during mixing, transporting, placing, and curing; and to overcome certain emergencies during concrete operations. It would be difficult to produce high-strength concrete mixtures without using chemical admixtures. A common practice is to use a super plasticizer in combination with a water-reducing retarder. The super plasticizer gives the concrete adequate workability at low water-cement ratios, leading to concrete with greater strength. The water-reducing retarder slows the hydration of the cement and allows workers more time to place the concrete. The effectiveness of an admixture depends on several factors including: type and amount of cement, water content, mixing time, slump, and temperatures of the concrete and air.

Sometimes, effects similar to those achieved through the addition of admixtures can be achieved by altering the concrete mixture-reducing the water-cement ratio, adding additional cement, using a different type of cement, or changing the aggregate and aggregate gradation.

In order to sufficiently reduce the water content of the mix and still maintain an acceptable workability, high-range water-reducing agents (super plasticizers) have to be used. In addition set-retarding agents and air-entraining admixtures may also be needed.

Super plasticizers are organic products or combinations of organic and non-organic components. They are surface active admixtures, consisting mostly of suffocated salts of melamine or naphthalene formaldehyde condensates. Some formulations may contain set-retarding, set-accelerating or deforming chemicals. An accelerated super plasticizers may be used to compensate for retarding actions of active ingredients present in some super plasticizers such as modified lignosulfonates. A modified retarding super plasticizer can be useful in low-slump concrete where the fluidity loss is sharp.

Super plasticizers are surface active agent and have water-reducing character. These are also known as high-range water reducers, plasticizers etc. This implies that it is possible to produce a concrete with lower water- to -cement ratio with their addition. High performance concrete (HPC) and high strength concrete (HSC) are generally made with high cementitiuos materials. It causes difficult in obtaining good workability and in homogeneous dispersion of the cementitiuos materials. This problem can be over comed by adding more water, but this decreases the strength. This creates the necessity of using water-reducing admixture. High cementitiuos materials and low water-to-binder ratio may create other problems such as early age cracking , it occurs due to loss of workability and very quick drying at the open surface caused by the dual effects of lack of bleeding , and bleed the lack of bleed water to move up to surface .

High heat of hydration is another major factor causing thermal cracking with high cement concrete. It is reported that the slag reduces the temperature rise during hydration. But does not give early high strength to the concrete. However, a combination of high range water reducer and fine ground slag which significantly improves the strength development can be a possible solution [11].

2.5 High Strength Concrete Proprieties

2.5.1 Stress-strain behavior in uniaxial compression

The stress–strain behavior of concrete is primarily influenced by the relative stiffness of the paste and aggregates, and the bond strength at the interfacial transition zone. All else equal, higher interfacial bond strength is achieved using rough as opposed to smooth textured aggregate. Therefore, for two coarse aggregates of the same size, shape, mineralogy, and stiffness, higher strength (and corresponding strain capacity) would be achieved using crushed stone compared to smooth gravel. [13]

Various investigators (Shah *et al.*, 1981, Jansen *et al.*, 1995) have reported higher strain capacities at maximum stress for high strength compared to conventional-strength concretes.

2.5.2 Modulus of elasticity

Modulus of elasticity is defined as the ratio of normal stress to Corresponding strain for tensile or compressive stresses below the proportional limit of a material. [13]

Thoman and Reade reported values for the modulus of elasticity determined as the slope of the tangent to the stress-strain curve in uniaxial compression at 25 percent of maximum stress from 4.2 x l06 to 5.2 x l06 psi (29 to 36 GPa) for concretes having compressive strengths ranging from (69 to 76 MPa).[13]

2.5.3 Poisson's ratio

Poisson's ratio under uniaxial loading conditions is defined as the ratio of transverse strain to the corresponding axial strain resulting from uniformly distributed axial stress below the proportional limit of the material. [16]

Experimental data on values of Poisson's ratio for high-strength concrete are very limited. Shideler and Carrasquillo reported values for Poisson's ratio of lightweight-aggregate high-strength concrete having uniaxial compressive strengths up to 10,570 psi (73 MPa) at 28 days to be 0.20 regardless of compressive strength, age, and moisture content. Values determined by the dynamic method were slightly higher.

Based on the available information, Poisson's ratio of high-strength concrete in the elastic range seems comparable to the expected range of values for lower-strength concretes. [3]

2.5.4 Compressive strength

The strength of concrete depends on a number of factors, including the properties and proportions of the constituent materials, degree of hydration, rate of loading, method of testing and specimen geometry. The properties of the constituent materials that affect the strength are the quality of fine and coarse aggregate, the cement paste and the paste-aggregate bond at the interfacial transition, zone. These, in turn, depend on the macro and microscopic structural features including total porosity, pore size and shape, pore distribution and morphology of the hydration products, plus the bond between individual solid components. Testing conditions including age, rate of loading, method of testing, and specimen geometry, profoundly influence measured strength. [12]

The strength development characteristics of high-strength concrete are different from those of conventional-strength concrete. Tests by Wild *et al.*(1995) showed that high-strength concrete with a W/B ratio of 0.35 (without silica fume) had a 7-day compressive strength that averaged 86 percent of the28-day strength when cured at 20°C (68°F). This same ratio for conventional strength concrete was in the range 60 to 70 percent. When silica fume was added to the high-strength concrete in the range 12 to 28 percent mass fraction of cement, the average ratio of the 7-day to the 28-day strengths was 76 percent when cured at 20°C (68°F). When the curing temperature was increased to 50°C (122°F), this ratio increases significantly to 97 percent, indicating that high curing temperatures can be very beneficial to early strength development in silica-fume high-strength concrete (Meeks and Carino, 1999).

Typically, strength gain in compression is much faster than strength gain in the transition zone bond. Changes in the strength of high-strength concrete over time are driven by two opposing factors— hydration and self-desiccation.Provided free moisture is available to anhydrate cementing particles, they will continue to form hydration products, and strength will continue to increase. Conversely, systems absent of free moisture may self-desiccate, in which case, measured strength over time could conceivably decrease. [12]

2.5.5 Tensile splitting strength

Dewar studied the relationship between the indirect tensile strength (cylinder splitting strength) and the compressive strength of concretes having compressive strengths of up to 12,105 psi (83.79 MPa) at 28 days.

He concluded that at low strengths, the indirect tensile strength may be as high as 10 percent of the compressive strength but at higher strengths it may reduce to 5 percent.

He observed that the tensile splitting strength was about 8 percent higher for crushed-rock-aggregate concrete than for gravel-aggregate concrete- In addition, he found that the indirect tensile strength was about 70 percent of the flexural strength at 28 days. The following equation for the prediction of the tensile splitting strength of normal weight concrete was recommended. [3]

2.5.6 Shrinkage

Little information is available on the shrinkage behavior of high-strength concrete. A relatively high initial rate of shrinkage has been reported, but after drying for 180 days there is little difference between the shrinkage of high strength and lower-strength concrete made with dolomite or limestone.Reducing the curing period from 28 to 7 days caused a slight increase in the shrinkage. Shrinkage was unaffected by changes in water-cement ratio but is approximately proportional to the percentage of water by volume in the concrete. Other laboratory studies and field studies have shown that shrinkage of high-strength concrete is similar to that of lower-strength concrete. Nagataki and Yonkers reported that the shrinkage of high strength concrete containing high-range water reducers was less than for lower-strength concrete. [3]

2.5.7 Creep

Parrott reported that the total strain observed in sealed high-strength concrete under a sustained loading of 30 percent of the ultimate strength was the same as that of lower-strength concrete when expressed as a ratio of the short term strain. Under drying conditions, this ratio was 25 percent lower than that of lower-strength concrete. The total long-term strains of drying and sealed high strength concrete were 15 and 65 percent higher, respectively, than for corresponding lower-strength concrete at a similar relative stress level. Ngab found little difference between the creep of high-strength concrete under drying and sealed conditions. The creep of high-strength concrete made with high range water reducers is reported to be decreased significantly. The maximum specific creep was less for high-strength concrete than for lower-strength concrete loaded at the same age. [3]

2.5.8 Permeability and Water-tightness

Concrete used in water-retaining structures or exposed to weather or other severe exposure conditions must be virtually impermeable or watertight. Water tightness is often referred to as the ability of concrete to hold back or retain water without visible leakage. Permeability refers to the amount of water migration through concrete when the water is under pressure or to the ability of concrete to resist penetration by water or other substances (liquid, gas, or ions). Generally, the same properties of concrete that make it less permeable also make it more watertight.

The overall permeability of concrete to water is a function of:

(1) thepermeability of the paste;

(2) the permeability and gradation of the aggregate;

(3) the quality of the paste and aggregate transition zone;

(4) the relative proportion of paste to aggregate.

Decreased permeability improves concrete's resistance to freezing and thawing, restoration, sulfate, and chloride-ion penetration, and other chemical attack. [15]

A low water-cement ratio also reduces segregation and bleeding, further contributing to water tightness. Of course watertight concrete must also be free from cracks, honeycomb, or other large visible voids. [16]

Chapter Three

Mix Design and Experimental Study

3.1- Introduction

Concrete mix proportions for high-strength concrete have varied widely ‘depending upon many factors. The strength level required, test age, material characteristics, and type of application have influenced mix proportions.

In addition, economics, structural requirements, manufacturing practicality, anticipated curing environment, and even the time of year have affected the selection of mix proportions. [3]

High-strength concrete mix proportioning is a more critical process than the design of normal strength concrete mixtures. Usually, specially selected pozzolanic and chemical admixtures are employed, and the attainment of a low water-cementations ratio is considered essential.

Many trial batches are often required to generate the data that enables the researcher to identify optimum mix proportions.

3 .2 Concrete mix designs:

Concrete mix design can be defined as the procedure by which , for any given set of concrete , the proportion of the constituent materials are chosen so as to produce a concrete with all the required properties for the minimum cost.

3-3 Required concrete properties:

The basic requirements for concrete are conveniently considered at two stages in its life. In its hardened state (in the completed structure) the concrete should have adequate durability, the required strength and also the desired surface finish.

In its plastic state, or the stage during which it is to be handled and compacted in its final form, it should be sufficiently workable for the required properties in its hardened state to be achieved with the facilities available on site.

This means that:

1- The concrete should be sufficiently fluid to be able to flow into and fill all parts of the from work, into which it is placed.

2- It should do so without any segregation or separation, of the constituent materials while being handled from the mixer or during placing.

3- It must be possible to fully compact concrete when placed in position.

4- It must be possible to obtain the required surface finish.

If concrete does not have the required workability in its plastic state, it will not be possible to produce concrete with the required, properties in its hardened state.

3-3-1 Durability:

Adequate durability of exposed concrete can frequently be obtained by ensuring full compaction, an adequate cement content and a low water – cement ratio, all of which contribute to producing a dense, impermeable concrete.

Other factors affecting durability are:

- **Aggregate:**

Aggregates constitute about 75% of the volume of concrete, so their properties have a large influence on the properties of the concrete [20]. Aggregates are granular materials, most commonly natural gravels and sands or crushed stone. The choice of aggregate is important particularly for concrete wearing surface and where improved fire resistance is required. Aggregate having high shrinkage properties should be used with caution in exposed concrete.

Durability is not a readily measured property of the hardened concrete. However, for a correctly designed concrete mix any increase in the water –

cement ratio on site, the associated reduction in durability will be accompanied by a reduction in concrete strength. The latter can be determined quite easily using control specimens and for this reason the emphasis in control testing is on the determination of concrete strength.

3.3.2 Strength:

The strength of the concrete is frequently an important design consideration particularly in structural applications where the load carrying capacity of a structural member may be closely related to the concrete strength. This will usually be the compressive strength although occasionally the flexural or indirect tensile strength may be more relevant. The strength requirement is generally specified in terms of a characteristic strength coupled with a requirement that the probability of the strength falling below it shall not exceed a certain value. An understanding of the factors affecting concrete strength on site, and of the probable variations in strength, is essential if such specifications are to have any real meaning at the mix design stage.

Difference in strength can also occur owing to variation in the quality of cement but the principal factor affecting the strength is the water cement ratio in the concrete mix. Once a suitable mix has been obtained the workability can be assessed quite satisfactorily by an experienced mixer operator, with periodic control tests of the workability. However, human error will inevitably result in some variation in the water – cement ratio either side of the desired value.

Any variation in mix proportion or significant changes in the aggregate grading will affect the quantity of water needed to maintain the required workability and this too will result in variation in the water – cement ratio and hence in concrete strength [19].

3-3-3 Compressive strength:

The compressive strength of concrete is taken as the maximum compressive load it can carry per unit area.

Concrete strength of up to 80N/mm^{-2} can be achieved by selective use of the type of cement, mix proportion, method of compaction and curing conditions. Concrete structures, except for road pavement, are normally designed on by steel reinforcement.

In the United Kingdom a 150 mm cube is commonly used for determining the compressive strength. The test specimen should be cured in water and crushed immediately after it has been removed from the curing tank [19].

The compressive strength of concrete is primarily dependent on the following:

1- Curing: duration, moisture content , temperature.

2- Age at testing .

3- Shape and size of specimen (cub or cylinder).

Testing procedure (applied load rate & moisture condition).

4- Compressive strength is considered as an index to assess the overall quality of concrete and it is generally assumed that an improvement in the compressive strength results in improvement of all other properties.

Hence strength investigations are generally centered on compressive

Strengths [21].

3-3-4 Workability:

The ease of placing, consolidating, and finishing freshly mixed concrete and the degree to which it resists segregation is called workability. Concrete should be workable but the ingredients should not separate during transport and handling.

The degree of workability required for proper placement of concrete is controlled by the placement method, type of consolidation, and type of concrete. Different types of placements require different levels of workability.

Factors that influence the workability of concrete are:

(1) The method and duration of transportation.

(2) Quantity and characteristics of cementations materials.

(3) Concrete consistency .

(4) Grading, shape, and surface texture of fine and coarse aggregates.

(5) Entrained air.

(6) Water content and water – cement ratio.

(7) Concrete and ambient air temperatures.

(8) Admixtures.

3-1-8 Water – cement ratio:

Water cement ratio gives the compressive strength of concrete at a given age. The lower the water – cement ratio, the greater is the compressive strength and vice versa[20].

3.4 Laboratory Investigation:

The following subsections present the details of the materials
used in the production of HSC and the related testing and specifications.

- **Aggregate:**

Aggregate are those parts of the concrete that constitute the bulk of the finished product. They comprise 60-80% of the volume of the concrete and have to be so graded that the entire mass of concrete acts as a relatively solid, homogeneous and dense. There are two types of aggregate:

- **Fine Aggregate**:

Locally available natural sand passing through 10 mm sieve and retained on 0.15 mm sieve Fin**e** aggregate (zone-II) confirming
BS 882

Coarse Aggregates:

Aggregates of size 20 mm and 10 mm were used (10 mm 31%, and 20mm 69% by weight) were used in the present investigation. The properties of fine aggregate and coarse aggregate are presented in Table (4-2) and (4-3) respectively.

- **Cement:**

Ordinary Portland cement (Sakhar Elsudan) was used throughout experimental program. Its physical properties were determined according to BS-12-1996; sufficient cement was reserved to avoid changing reference cement. The results were presented in Table (4.1).

- **Water:**

natural water that is drinkable

* (Water that is safe to drink is safe to use in concrete) [19].

- Super plasticizer (Chemical admixture) :

MCS -100 high range water reducer super plasticizers and retarder admixture Dose from 0.5to1.9 liter per100Kg of cement depending on Workability and Water Reduction required and the optimum dose of MCS- 100 can be established After Laboratory trail Mix.

Silica fume (Mineral admixture):

3.2.1 Slump cone test:

The slump test is the most commonly used method The slump test is suitable for slumps of medium to high workability, slump in the range of 0 – 70 mm; The results were presented in Table (4-5).(4-6.

3.2.3 Testing of hardening concrete:

- **Compressive Strength of Concrete:**

Concrete cubes of 150 X 150 X 150 mm dimension were casting for compressive strength. They have tested for compressive strength after 3, 7, and 28days of water curing. The compressive strength was determined according to BS 1881: part 116, 1986.

Procedure of Compressive strength test:

- After finishing all other tests, the specimens (cubes) are ready for Compressive Strength Test.

- Each specimen to be fixed in the compressive machine in order to applied load on it.
- The load is applied gradually.
- Failure load of the specimen is recorded.

3.5 Mixes Proportions

Reference mix with super plasticizer 1litter/100kg cement

Characteristic strength:	specified	60 N/mm^2 at 28 days. Proportion defective percent=5%
Standard deviation:	Fig 3	8 N/mm^2
Margin	C1	1.64 * 8 = 13 N/mm^2
Target mean strength	C2	60 + 13 =73 N/mm^2
Cement type	Specified	(OPC)
Aggregate type:	coarse crushed	
Aggregate type:	fine Uncrushed	
Free-water/cement ratio	Table 2 Fig 4	0.33
Slump	Specified	(mm)
Maximum aggregate size	Specified	20 mm
Free- water content	Table 3	170 kg /m^3.
Cement content	C3	515 Kg / m^3.
Relative density of aggregate		2.7 Known/assumed
Concrete density	Fig 5	2460 Kg/m3
Total aggregate content	C4	(2460) – (515) – (170) = 1775 kg / m^3.
Proportion of fine aggregate	Fig 6	0 .38 percent
Fine aggregate content		1775 * 0.38 = 675 kg / m^3.
coarse aggregate content		1775 – 675 = 1100 kg / m^3.

Quantities per m3 :

Cement	Water (kg)	Fine	Coarse aggregate (kg)

(kg)		**aggregate (kg)**	**20mm**	**10mm**
515	170	675	733	367

Table (3-1) Mix proportion of silica fume:

Type of Concrete	**Mix Designation**	**S.F cement ratio %**	**SP content**
without additive	S.F-0%+SP	0	0.8lit/100kg cm
With Additive	S.F-5%+SP	5	0.8lit/100kg cm
	S.F-5%+SP	5	1lit/100kg cm
	SF-10%+SP	10	1lit/100kg cm
	SF-10%+SP	10	1.2 lit/100kg cm
	SF-15%+SP	15	1.2 lit/100kg cm

Table (3-2) Mix Proportion of Concrete (Kg/m3):

Mix	w/c.m	Cement (kg)	Fine Aggregate (Kg)	Coarse Aggregate (Kg)	Water (Kg)	Super Plasticizers(L/100kgcm)	Silica Fume(Kg)
Mix1	0.33	515	675	1100	170	0.8	0
Mix2	0.33	489	675	1100	170	0.8	25.75
Mix3	0.33	489	675	1100	170	1	25.75
Mix4	0.33	463.5	675	1100	170	1	51.5
Mix5	0.33	463.5	675	1100	170	1.2	51.5
Mix6	0.33	437.8	675	1100	170	1.2	77.3

- **Concrete Water Absorption Tests**

The produced specimens were dried until the mass became constant (WO). Then the specimens were immersed in clean water at 28 days. After the desired immersion period had passed, the specimens were taken out and the surfaces were wiped quickly with wet cloth and then weighted (W1) immediately as illustrated in Table (4.1)

The rate of water absorption can be calculated from the following formula:

Water absorption (%) = {(W1 – WO)/WO} *100

3-6 Experimental program:

In this study concrete which has high grade is used. Beside the ordinary reference mixes, chemical and mineral admixtures are used in this study.

The study covered the following phases:

3-6-1 Preliminary tests :

1- **standard tests of cement :**
    - Setting time test (initial & final setting time).
    - Compressive strength test.

2- standard tests for fine aggregate :

- sieve analysis
- silt content

3-6-2 Testing program:

In this study The testing program as follow

1- Carry out the standard tests for materials (ordinary Portland cement, coarse aggregate, fine aggregates) which brought from the known sources in Khartoum state.

2- Design concrete mixes for w/c ratio 0.33 with chemical admixture (Super plasticizer) (0.8litters/100Kg cementation material) to achieve high strength concrete with high workability.

3- Making trials mixes for the designed mixtures above obtain the required workability.

4- measuring the workability (slump test) for each mixtures (modified & unmodified) for mix design .

5- Casting nine cubes for each unmodified mixes and nine cubes for each mix containing super- plasticizer and silica fume, and testing their compressive strength at the age 3, 7 and 28 days,

6- Casting fifteen cubs ,three cubs for unmodified mixes and three cubs for each mix containing super- plasticizer, and silica fume and testing their permeability

7- all specimens cured in fresh potable water.

8- Analyzing the results and recording notifications.

Chapter four

The Results and Discussion

4.1 Introduction

In this research, an intensive laboratory investigation, for the effect of micro Silica and super plasticizer on both fresh and hardened concrete mixes has been conducted. Preliminary tests for local ordinary Portland cement and aggregate used in the research have been carried out. In addition, large numbers of experiments concerning workability and compressive strength of concrete mixes, when adding superplasticizer and micro silica have been done. The ratios of super plasticizer added were 0.8 (as a reference mix), 1 and 1.2 Litre/ 100Kg cement for concrete ages of 3, 7 and 28 days by preparing 12 cubes for each sample. The fresh concrete mixes were casted in standard test moulds of 150mm cubic –according to BS1881: sections 108 and 116 (Also SABS standard method 863), where as a standard slump cone of 300mm high, 150mm diameter cylinder – according to ASTM standard was used for measuring concrete slumps. The concrete mix design sheet is attached in appendix (B). The results of these experiments are shown in the following tables and figures.

4.2 Results Of Preliminary Tests:

4.2.1 results of cement tests

The results of cement tests are shown in table (4-1)

Table (4.1): Results of cement Test

Test	Results	Requirements of BS 12-1996
Consistency	29.0%	26 -32%
Setting Time		
a) Initial	2 hrs	Not less than 60 min (-15 min)
b) Final	3 hrs: 10 min	Not more than 10 hrs.
Compressive Strength		
a) 2days		Equal or Greater than 10 N/mm^2
1	17.6 N/mm^2	
2	17.2 N/mm^2	
3	17.32 N/mm^2	
b) 28 days		Equal or Greater than 42.5 N/mm2
1	45.6 N/mm^2	
2	44.1 N/mm^2	
3	46.2 N/mm^2	

4.2.2. Results of Aggregate Test

Table (4.2): Results Of Fine Aggregate Sieve Analysis

Sieve No mm	**Retained (g)**	**Percentage retained**	**Percentage Passing**	**BS Zone 2 BS 882**
4.75	93	4.7	95.3	89-100
2.36	163	8.2	87.1	65-100
1.18	332	16.7	70.4	45-100
0.6	347	17.5	52.9	25-80
0.3	792	39.9	12.99	5-48
0.15	180	9	3.93	0-5
0.075	63	3.2	0.76	
Pan	14	0.7	0	
Total weight	1984g			

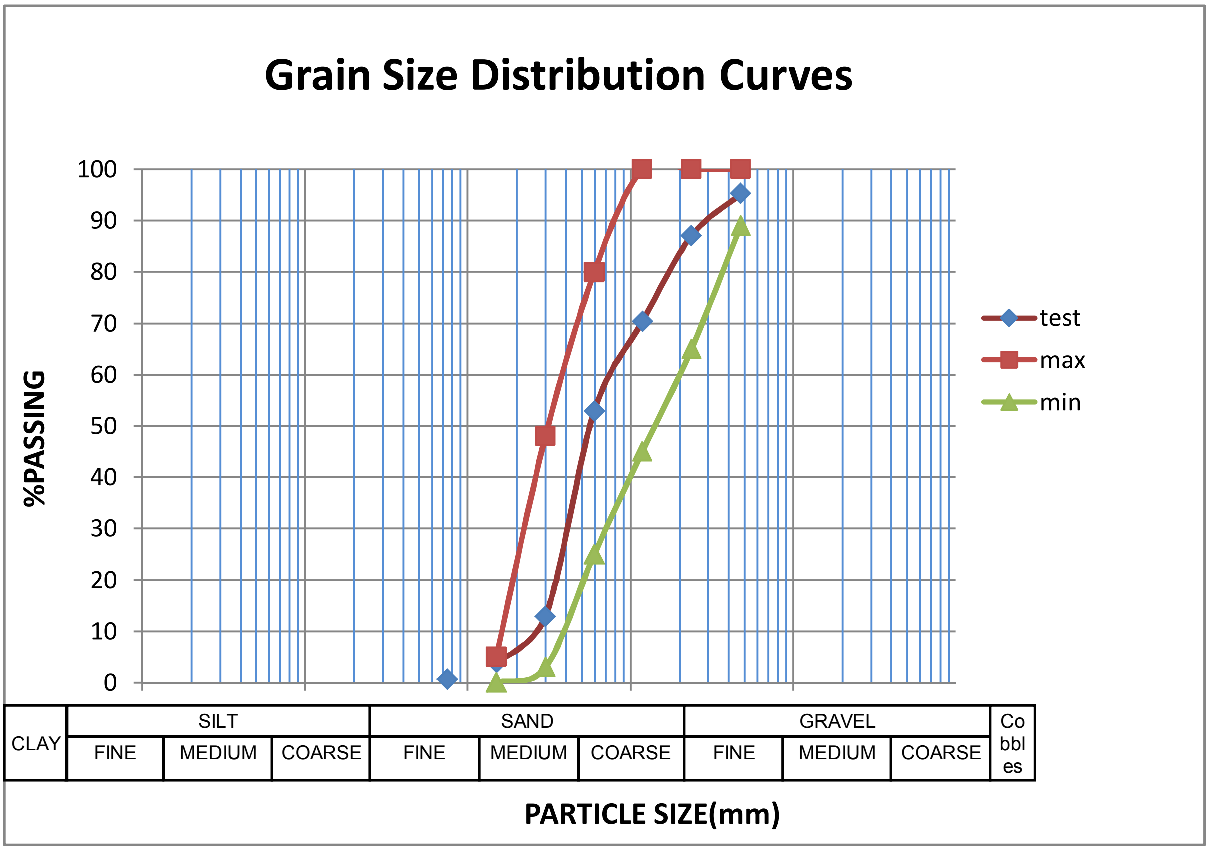

Fig (4.1):Result of Grain Size of fine Aggregate Test

4.2.1.2 Results Of Silt Content:

Silt content in fine aggregate should not be more than 3% of the total weight of sand according to the (BS882) [23]. Sample of sand weighted and washed and after that dried in furnace and the percentage of loss weight calculated, found the silt content in fine aggregate about (2) %.

The results of sieve tests are shown in Table (4-3), (4-4) and (4-5).

Table (4-3): Results Of Grading and Physical Properties of Coarse aggregate (20mm and 10mm)

Properties	**Coarse Aggregate(20mm)**	**Coarse Aggregate(10mm)**
Grading of Aggregate		
Sieve size(mm)	Passing%	
25	100	100
19.5	93	100
12.5	28.5	100
9.5	2.3	90
4.75	0	16.7
Physical properties of Aggregates		
Specific gravity	2.7	2.8
Absorption	1.5	1.42

Table (4.4): Results Of Grading of crushed Coarse aggregate (combination 20mm and 10mm)

Sieve No mm	**Retained (g)**	**Percentage retained**	**Percentage Passing**	**BS 1882**
25	0	0	100	100
19	156	5.2	94.8	90-100
12.5	1257	42.2	52.6	40-80
9.5	584.5	19.63	32.9	30-60
4.75	678.5	22.8	10.14	0-10
pan	302	10	0	

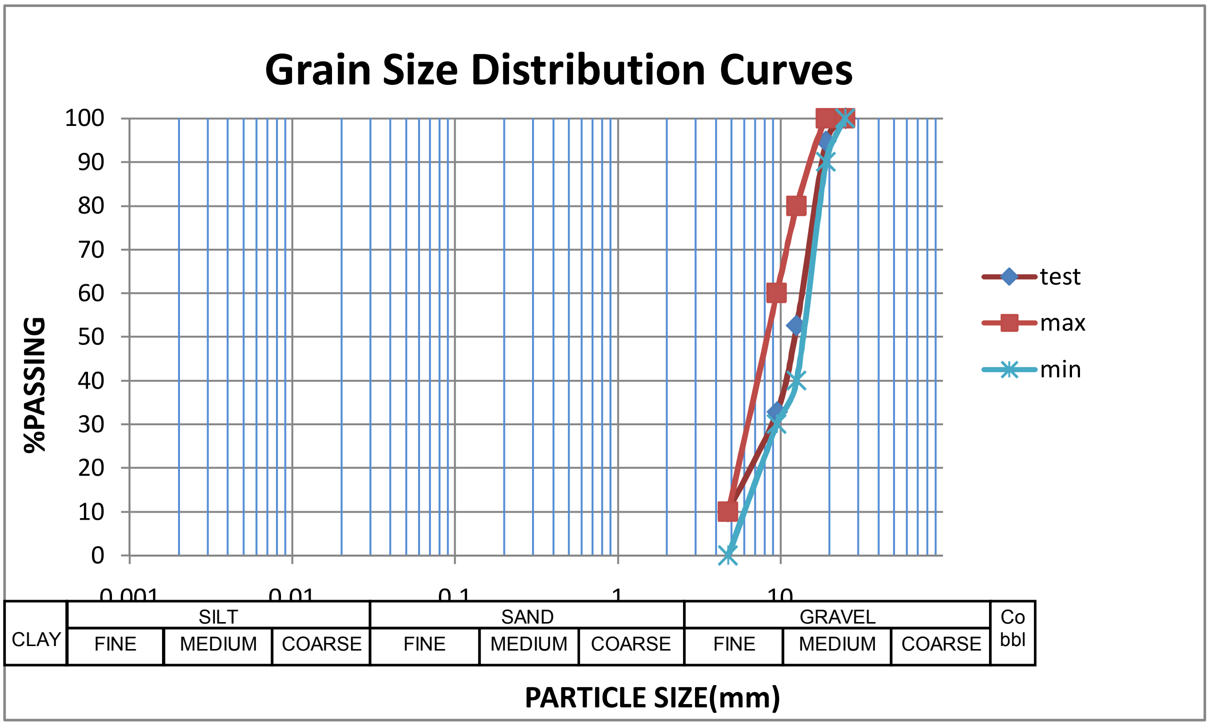

Fig (4.2): Results Of Grain Size of Coarse Aggregate Test

It is clear that the grading of coarse aggregate are well graded and grading of fine aggregate classified zone 2 according to BS882, 1992.

4.3 Results Of workability Test for Fresh Concrete:

Table (4.5) Results of workability (slump) Test of Fresh Concrete Contening (Silica Fume +0.8lit/100Kg c.m)

Silica Fume%+(o.8lit/100Kg cm)	0.0%	5%	10%	15%
Slump (mm)	60	40	20	0

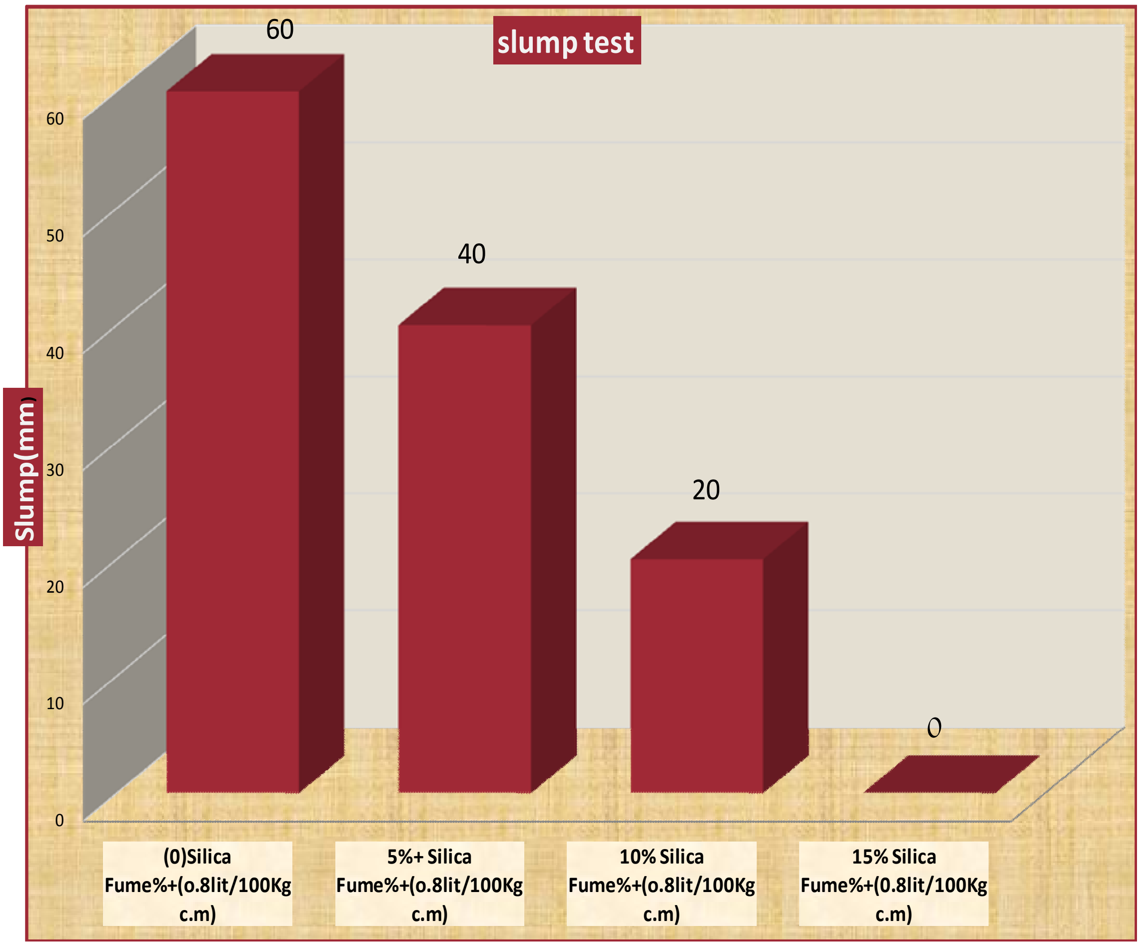

Fig (4.3)A: Results of Slump Test of Concrete Contenting(0, 5% ,10%,And 15%) silica fume and Super plasticizer

Table (4.6) Results of workability (slump) test for Fresh Concrete Containing silica fume(0,5%,10%,And15%)And (0.8,1,And 1.2litSP/100Kg cm)

Silica Fume% + (o.8lit/100Kg cm)	5% Silica Fume% + (o.8lit/100 Kg cm)	5% Silica Fume% + (1lit/100 Kg cm)	10% Silica Fume% + (o.8lit/100 Kg cm)	10% Silica Fume% + (1lit/100Kg cm)	10% Silica Fume% + (1.2lit/100 Kg cm)	15% Silica Fume% + (1.2lit/100Kg cm)
60	40	70	20	40	70	40

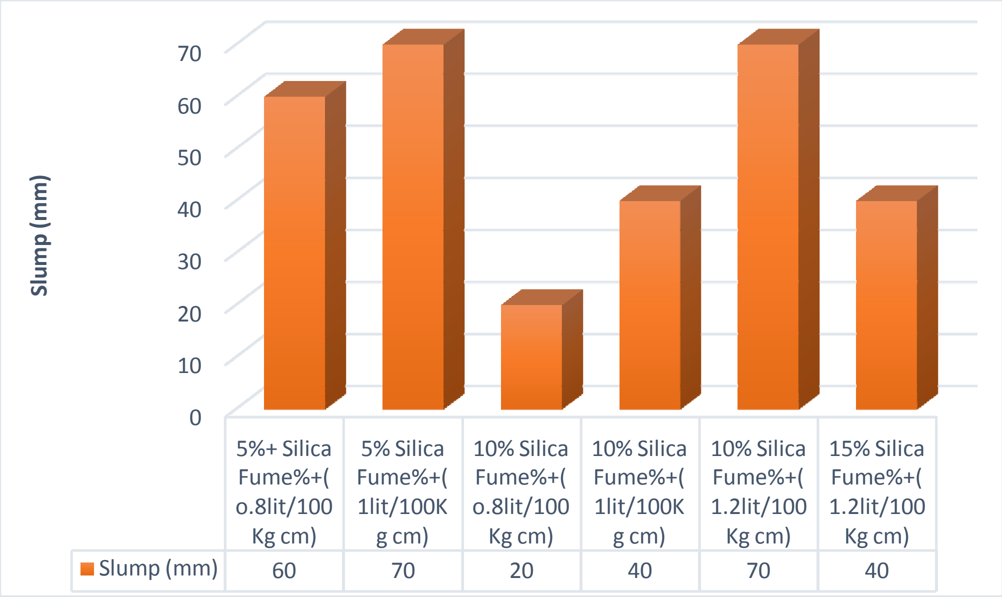

Fig (4.4): Relationship between Results of Slumps and Silica fume%

4.4 Results Of concrete compressive Strength Test:

Table (4-7) Results of compressive strength for control mix with w/c (0.33) (Silica fume 0% +0.8 lit SP /100 kg cement)

Type and doses of additive	**Age**	**Slump (mm)**	**Weight of cube (kg)**	**Ultimate Load (kN)**	**Compressive strength (N/mm^2)**	**Mean Compressive strength (N/mm^2)**
Dosage(0)	3 days	60mm	8.752	862.6	38.34	38.6
			8.732	877.5	39	
			8.742	866.3	38.5	
Dosage(0)	7 days		8.311	1082.5	48.11	49.5
			8.204	1157.4	51.44	
			8.29	1102.5	49	
Dosage(0)	28day		8.371	1301.4	57.08	59
			8.348	1355.18	60.23	
			8.354	1345.5	59.8	

Table (4-9) Results of compressive strength modified by (Silica fume 5% +0.8 lit SP /100 kg cement)

Type and doses of additive	Age	Slump (mm)	Weight of cube (kg)	Ultimate Load (kN)	Compressive strength (N/mm^2)	Mean Compressive strength (N/mm^2)
Dosage (5%) + 0.8litSP/100 Kg cm	3 days	40mm	8.578	834.1	37.06	37.5
			8.631	889.2	39.52	
			8.00	855	38	
Dosage (5%) + 0.8litSP /100Kg cm	7 days		8.470	866.3	38.5	41.8
			8.501	896.4	40	
			8.773	773.3	34.37	
Dosage (5%) + 0.8 lit SP /100Kg cm	28 day		8.397	959.1	42.63	43
			8.44	921.3	43.94	
			8.472	1025.3	45.6	

Table (4-9) Results of compressive strength modified by (Silica fume 5% +1 lit SP /100 kg cm)

Type and doses of additive	**Age**	**Slump (mm)**	**Weight of cube (kg)**	**Ultimate Load (kN)**	**Compressive strength (N/mm^2)**	**Mean Compressive strength (N/mm^2)**
Dosage(5%) +1litSP/100 kg cm)	3 days	70mm	8.543	541.4	24.05	22.4
			8.531	439.9	19.54	
			8.628	531.1	23.6	
Dosage(5%) +1litSP/100 kg cm)	7 days		8.587	550.8	24.5	26.4
			8.377	636.4	28.3	
			8.45	594	26.4	
Dosage(5%) +1litSP /100kg cm)	28day		8.438	1338.6	59.5	55.7
			8.483	1236	54.93	
			8.644	1187	52.74	

Table (4-10) Results of compressive strength modified by (Silica fume 10% +1lit SP /100 kg cm)

Type and doses of additive	Age	Slump (mm)	Weight of cube (kg)	Ultimate Load (kN)	Compressive strength (N/mm^2)	Mean Compressive strength (N/mm^2)
Dosage (10%) +1 lit SP /100 kg c.m	3 days	40mm	8.284	671.8	30	32
			8.360	774.8	34.4	
			8.322	774.5	32.2	
Dosage (10%) +1 lit SP /100 kg c.m	7 days		8.360	774.8	34.4	36
			8.515	849.1	37.74	
			8.342	811.6	36.07	
Dosage (10%) +1lit SP /100 kg c.m	28 day		8.359	1025.8	45.6	45.9
			8.448	1037.3	46.1	
			8.360	1032.8	45.9	

Table (4-11) Results of compressive strength modified by (Silica fume 10% +1.2lit SP /100 kg cm)

Type and doses of additive	**Age**	**Slump (mm)**	**Weight of cube (kg)**	**Ultimate Load (kN)**	**Compressive strength (N/mm^2)**	**Mean Compressive strength (N/mm^2)**
Dosage (10%) +1.2lit SP /100 kg c.m	3 days	70mm	8.824	642.8	28.6	28.57
			8.756	642.2	28.54	
			8.79	642.83	28.57	
Dosage (10%) +1.2lit SP /100 kg c.m	7 days		8.647	879.9	39	39
			8.551	872.3	38.77	
			8.663	887.4	39.44	
Dosage (10%) +1.2lit SP /100 kg c.m	28 day		8.695	1025.8	45.6	45
			8.448	990	44	
			8.584	1026	45.8	

Table (4-12) Results of compressive strength modified by (Silica fume 15% +1.2 lit SP /100 kg c.m)

Type and doses of additive	Age	Slump (mm)	Weight of cube (kg)	Ultimate Load (kN)	Compressive strength (N/mm^2)	Mean Compressive strength (N/mm^2)
Dosage (15%) +1.2 lit SP /100 kg c.m	3 days	40mm	8.458	680.8	30.25	30.4
			8.540	687.3	30.54	
			8.499	683.9	30.4	
Dosage (15%) +1.2 lit SP /100 kg c.m	7 days		7.231	781.8	34.75	34.4
			7.266	767.5	34.11	
			8.515	774.7	34.43	
Dosage (15%) + 1.2 lit SP /100 kg c.m	28 day		8.459	887.1	39.42	39
			8.506	875.8	38.93	
			8.497	864.7	38.43	

Table (4-13) Results Of compressive strength at 3 days (Silica fume +(0.8,1,and 1.2) lit SP /100 kg cm)

Type and doses of additive	Age	Slump (mm)	Weight of cube (kg)	Ultimate Load (kN)	Compressive strength (N/mm^2)	Mean Compressive Strength (N/mm^2)
Dosage(0) +0.8 lit SP /100 kg c.m)	3days	60mm	8.752	862.6	38.34	38.6
			8.732	877.5	39	
			8.742	866.3	38.5	
Dosage (5%) +0.8 lit SP /100 kg c.m)	3days	40mm	8.578	834.1	37.06	38.2
			8.631	889.2	39.52	
			8.542	855	38	
Dosage (5%) +1lit SP /100 kg c.m)	3days	70mm	8.543	541.4	24.05	22.4
			8.531	439.9	19.54	
			8.628	531.1	23.6	
Dosage (10% +1lit SP/100 kg c.m)	3days	40mm	8.284	671.8	30	32
			8.360	774.8	34.4	
			8.322	774.5	32.2	
Dosage (10% +1.21lit SP/100 kg c. m)	3days	70mm	8.824	642.8	28.6	28.6
			8.756	642.2	28.54	
			8.79	642.83	28.57	
Dosage (15% +1.2 SP/100 kg c.m)	3days	40mm	8.458	680.8	30.25	30.4
			8.540	687.2	30.54	
			8.499	683.9	30.4	

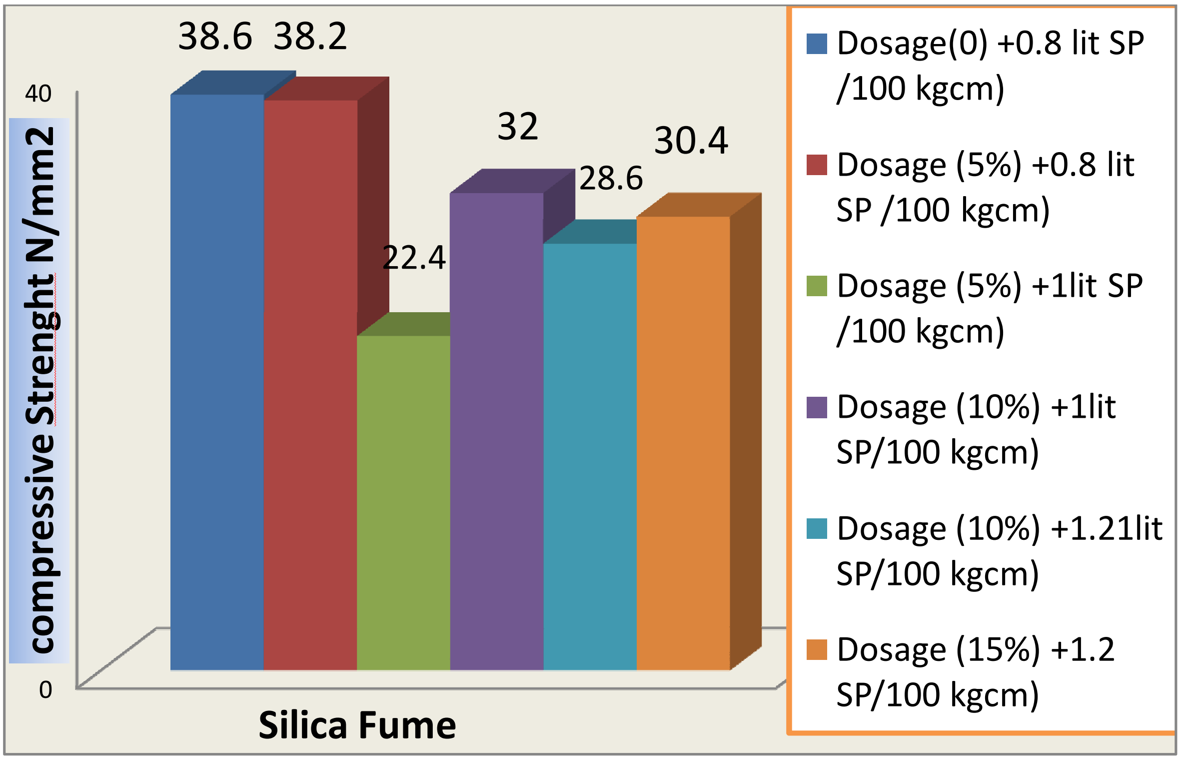

Fig (4.5): compressive strength Changing With different ratios of super plasticizer and silica fume at 3 days of age

Table (4-14) Results Of compressive strength at 7 days (Silica fume +(0.8,1,and 1.2) lit SP /100 kg c.m)

Type and doses of additive	**Age**	**Slump (mm)**	**Weight of cube (kg)**	**Ultimate Load (kN)**	**Compressive strength (N/mm^2)**	**Mean Compressive Strength (N/mm^2)**
Dosage(0)+0.8 lit SP /100 kg c.m	7 days	60mm	8.311	1082.5	48.11	49.5
			8.204	1157.4	51.44	
			8.29	1102.5	49	
Dosage (5%) +0.8 lit SP /100 kg c.m	7days	40mm	8.470	866.3	38.5	37.6
			8.501	896.4	40	
			8.773	773.3	34.37	
Dosage (5%) +1 lit SP /100 kg c.m	7days	70mm	8.587	550.8	24.5	26.4
			8.377	636.4	28.3	
			8.45	594	26.4	
Dosage (10%) +1 lit SP /100 kg c.m	7days	40mm	8.360	774.8	34.4	36
			8.515	849.1	37.74	
			8.342	811.6	36.07	
Dosage (10%) +1.2 lit SP /100 kg c.m	7days	70mm	8.647	879.9	39	39
			8.551	872.3	38.77	
			8.663	887.4	39.44	
Dosage (15%) +1.2 lit SP /100 kgcm	7days	40mm	7.231	781.8	34.75	34.4
			7.266	767.5	34.11	
			7.248	774.7	34.43	

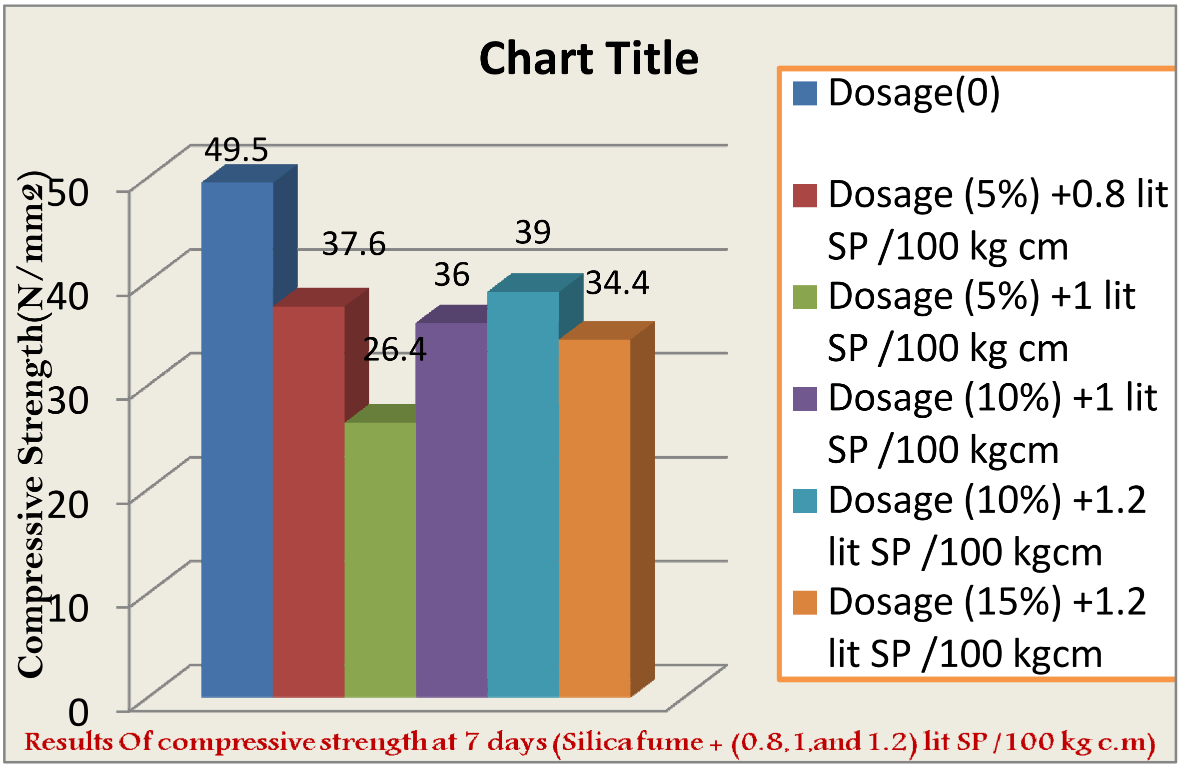

Fig (4.6): compressive strength Changing With different ratios of super plasticizer and silica fume at 7 days of age

Table (4-15) Results Of compressive strength at 28 day (Silica fume +(0.8,1,and1.2 lit SP /100 kg cm)

Type and doses of additive	Age	Slump (mm)	Weight of cube (kg)	Ultimate Load (kN)	Compressive strength (N/mm^2)	Mean Compressive strength (N/mm^2)
Dosage(0) + 0.8lit SP /100 kg cm	28 days	60mm	8.371	1301.4	57.08	59
			8.348	1355.18	60.23	
			8.341	1345.5	59.8	
Dosage (5%) 0.8lit SP /100 kg cm	28 days	40mm	8.397	959.1	42.63	44
			8.44	921.3	43.94	
			8.472	1025.3	45.6	
Dosage (5%) 1lit SP /100 kg cm	28 days	70mm	8.438	1338.6	59.5	55.7
			8.483	1236	54.93	
			8.644	1187	52.74	
Dosage (10%) +1lit SP /100 kg cm	28 days	40mm	8.359	1025.8	45.6	46
			8.448	1037.3	46.1	
			8.360	1032.8	45.9	
Dosage (10%) +1.2 lit SP /100 kg cm	28 days	70mm	8.695	1025.8	45.6	45
			8.448	990	44	
			8.584	1026	45.8	
Dosage (15%) +1.2 lit SP /100 kg cm	28 days	40mm	8.459	887.1	39.42	39
			8.506	875.8	38.93	
			8.497	864.7	38.43	

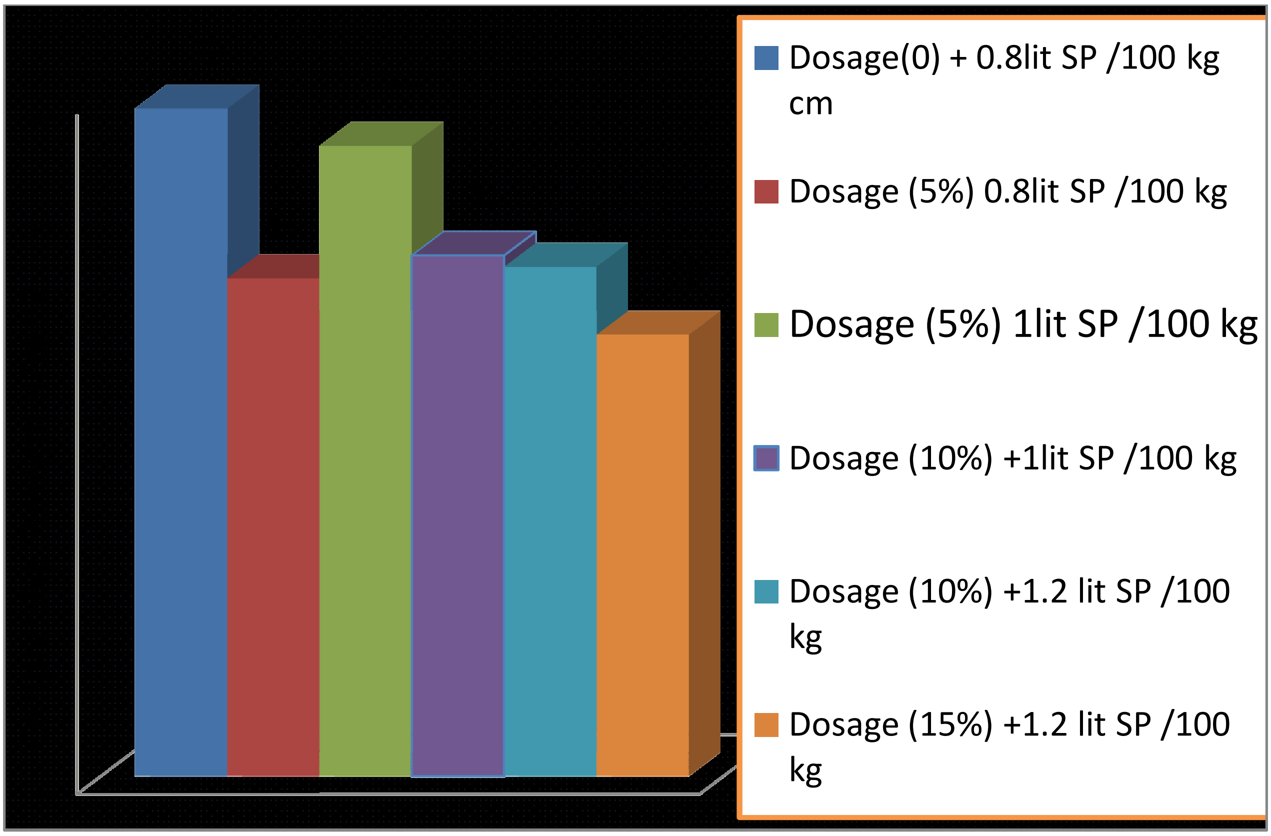

Fig (4.7): compressive strength Changing With different ratios of super plasticizer and silica fume at 28 days of age

Table (4-16) Result Of Compressive strength changing with time for mixes containing (SF+ SP /100 kg)

Time (days)	0% SF+0.8litSP/100kg c.m	5% SF+0.8litSP/100kg c.m		5%SF+ 1litSP/100kg c.m	
	Strength	Strength	Decrease%	Strength	Decrease %
3	38.6	37.5	2.8	22.4	41.9
7	49.5	41.8	15.6	26.4	46.7
28	59	43	27	55.7	5.6

Time (days)	10% SF+1litSP/100kg cm		10% SF+1.2litSP/100kg cm		15% SF+1litSP/100kg cm	
	Strength	Decrease%	Strength	Decrease%	Strength	Decrease%
3	32	17	28.57	26	30.4	21.3
7	36	27.3	39	21.2	34.4	30.5
28	45.9	22.2	45	23.7	39	33.9

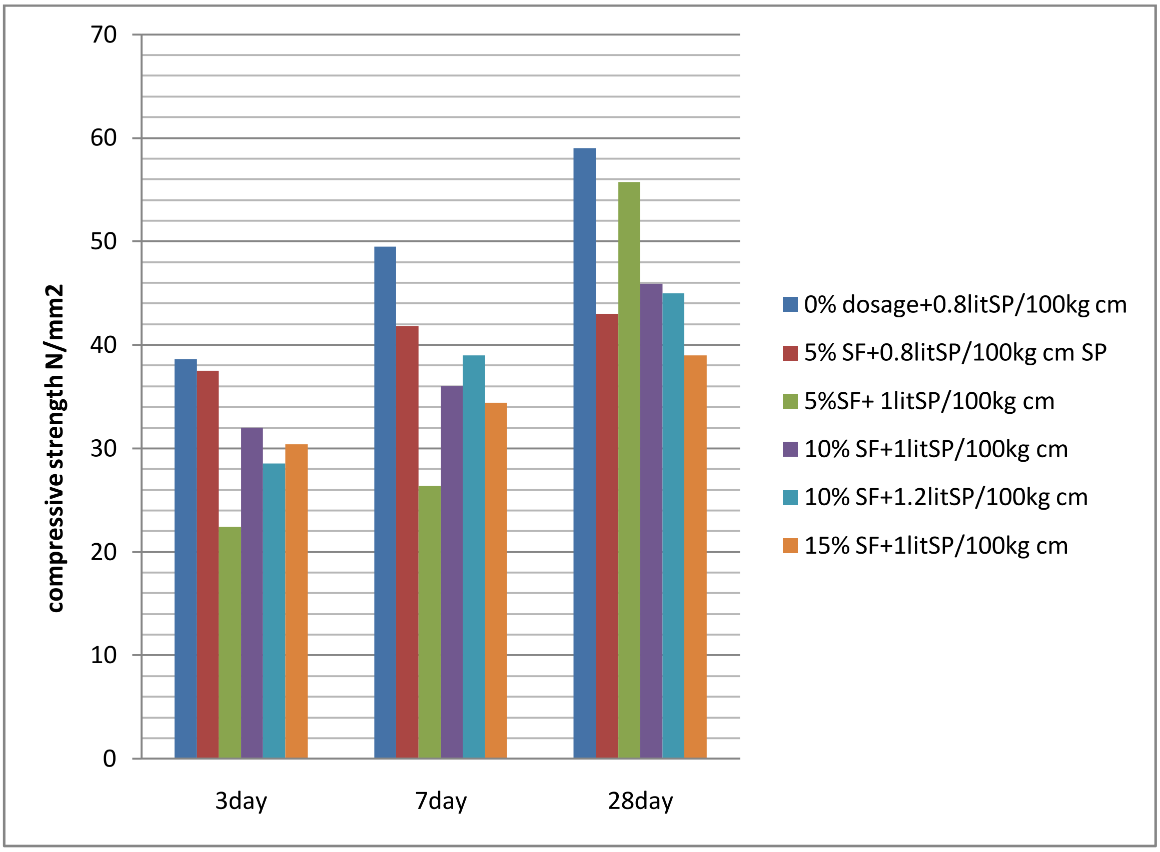

Fig (4.8): Result Of Compressive strength changing with time for mixes containing (SF+ SP /100 kg)

4.5 Results of Concrete Water Absorption Tests

Table (4-17): Results of absorption after 28 days

Silica fume %+super plasticizer	**Initial weight**	**Final weight**	**Differences**	**Absorption (%)**
Dosage (0) + 0.8lit SP /100 kg cm	8.321	8.580	0.259	3
Dosage (5%) + 1lit SP /100 kg cm	8.120	8.502	0.382	4.7
Dosage (10%) + 1lit SP /100 kg cm	8.213	8.623	0.41	5
Dosage (10%) + 1.2lit SP /100 kg cm	8.025	8.323	0.298	3.7
Dosage (15%) + 1.2lit SP /100 kg cm	8.232	8.624	0.392	4.8

4.6 Discussions

4.6.1 Preliminary Tests results and observations

Tests were carried out to ensure that the main constituents of concrete (cement & aggregates) are adequate and conforming with the requirements of the standards.

4.6.2 Workability Results:

The slump test was used as a measure of consistency when admixtures were used with ordinary reference mix having w/c ratio 0.33. Slumps of ordinary reference mix 60 mm presented in table (4-6). Slumps of mixes containing following different percentage of silica fume and super plasticizer:

1- 5% silica fume and 0.8L S.P/100 Kg of cementations material
2- 10% silica fume and 0.8L S.P/100 Kg of cementations material
3- 15% Silica fume and 0.8L S.P /100 Kg of cementations material
4- 5% silica fume and 1.0 L S.P/100 Kg of cementations material
5- 10% Silica fume and 1.0 L S.P/100 Kg of cementations material
6- 10% silica fume and 1.2L S.P/100 Kg of cementations material
7- 15% Silica fume and 1.2L S.P /100 Kg of cementations material

The slump measures are 40mm, 20mm, No slump ,70 mm, 40mm, 70mm, ,and 40mm respectively.

In general, when the percentage replacement of cement by silica fume increase the workability decrease.

As observed with constant amount of super plasticizer (0.8Lit SP/100 Kg of cementations material) the workability of mix containing higher percent of silica fume was low as shown in table (4-3).

As appeared when replaced 15% of cement by silica fume there was no slump (slump=0) .

4.6.3 compressive Strength Results:

The OPC replaced by silica fume (S.F) to presents a laboratory investigation on the compressive strength of concrete.

The experimental results in table (4-13) and fig (4-5) indicate that the three days' compressive strength decreased as the dosage of silica fume.

The replaced of 5% silica fume and 0.8Lit SP/100 Kg of cementations material decreased the three days compressive strength from 38.6 N/mm^2 to 38.2 N/mm^2 (1%) from the reference concrete mix, but further increase of silica fume from (5% to 10%) and 1Lit SP/100 Kg of cementations material increased the three days compressive strength only from 22.4 N/mm^2 to 32 N/mm^2 (42.8 %).

but further increase of silica fume from (10% to 15%)and 1.2Lit SP/100 Kg of cementations material increased the three days compressive strength only from 28.6 N/mm^2 to 30.4 N/mm^2 (6.3%).

The experimental results in table (4-14) and fig (4-6) indicate that the seven days' compressive strength decreased as the dosage of silica fume.

The replaced of 5% silica fume and 0.8Lit SP/100 Kg of cementations material decreased the seven days compressive strength from 48.5 N/mm^2 to 37.6 N/mm^2 (22.5%) from the reference concrete mix, but further increase of silica fume from (5% to 10%)and 1Lit SP/100 Kg of cementations material increased the seven days compressive strength only from 26.4 N/mm^2 to 36 N/mm^2 (37.8 %).

but further increase of silica fume from (10% to 15%) and 1.2Lit SP/100 Kg of cementations material decreased the seven days compressive strength only from 39N/mm^2 to 34.4 N/mm^2 (11%).

The experimental results in table (4-15) and fig (4-7) indicate that the 28 days' compressive strength decreased as the dosage of silica fume.

Replacement of 5% silica fume and 0.8Lit SP/100 Kg of cementations material decreased the 28 days compressive strength from 59 N/mm^2 to 44 N/mm^2 (25.4%) from the reference concrete, but further increase of silica fume from (5% to 10%) and 1Lit SP/100 Kg of cementations material the decreased the 28 days compressive strength only from 55.7 N/mm^2 to 46 N/mm^2 (17.4 %).

but further increase of silica fume from (10% to 15%)and 1.2Lit SP/100 Kg of cementations material the decreased the 28 days compressive strength only from 45 N/mm^2 to 39 N/mm^2 (13.3%).

As the previse studies approved that the replacement of silica fume lead to increase compressive strength ,but in this study the addition of silica fume lead to unexpected results.

4.3.3 Absorption:

small particles size, of the silica fume (SF) occupies the voids between the cement grains, acting as a filler and reducing the porosity. But in this experimental the used silica fume leaded to inverse results.

In another side, the absorption are fluctuating irrespective to ratios of super plasticizer. Table (4.18) shows that the values of absorption decreased with increasing super plasticizer ratios.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

This research was conducted to study the effect of silica fume (S.F) on the properties of fresh and hardened concrete.

The properties investigated are workability (slump) and compressive strength. From the results of this research it can be concluded that:

- There was negative effect of replacement silica fume and super plasticizer on the properties of fresh concrete occurred in all ratios of this additive when adding to concrete mixes .
- It is observed that slumps of mixes containing ratios of super plasticizer and silica fume much lower than that of the ordinary reference mix (slump = 60 mm) for the same percentages of super plasticizer. However, very high dosages of SP tend to impair the cohesiveness of concrete.——
- It is noticed that all ratios of SP added to concrete mixes increased the compressive strengths much more than that of normal concrete mix.
- It is found that the higher compressive strength in reference control and it decreased when the percentage replaced of silica fume increase.
- It is observed that the values of absorption showed no steady state of changes with respected to the used ratios of super plasticizer and silica fume.

5.2 RECOMMENDATIONS

1- From this research and the results obtained, it can be recommended that:

- Investigate the validity of silica fume using the chemical and physical laboratories test to be sure its valid.
- Study the ability of use local supplementary materials in high strength concrete and study their effect with silica fume.
- It is preferable to make more trial mix to determine the optimum ratios of silica fume and super plasticizer before use in main mix to obtain suitable slump and high compressive strength.
- The silica fume should be save in a good condition.

2 -There are several areas in concrete technology, as related to admixtures, that need to be investigated in the future, such areas include, but are not limited to, the following:

- Studying the possibility of reducing cement content with addition of super plasticizers and mineral additives such as local pozzolanic materials or silica dust or fly ash.
- Conducting further studies in this field for improving workability and compressive strength of concrete of different grades using other additives.

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Appendix (A)

Data Sheet of Super plasticizer

B.1:Tables and charts for mix design:

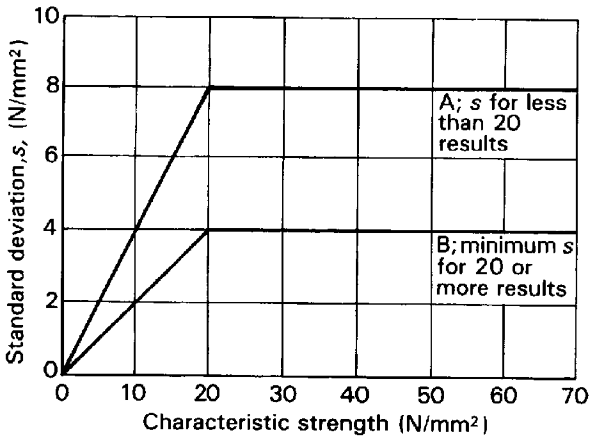

Figure 3
Relationship between standard deviation and characteristic strength

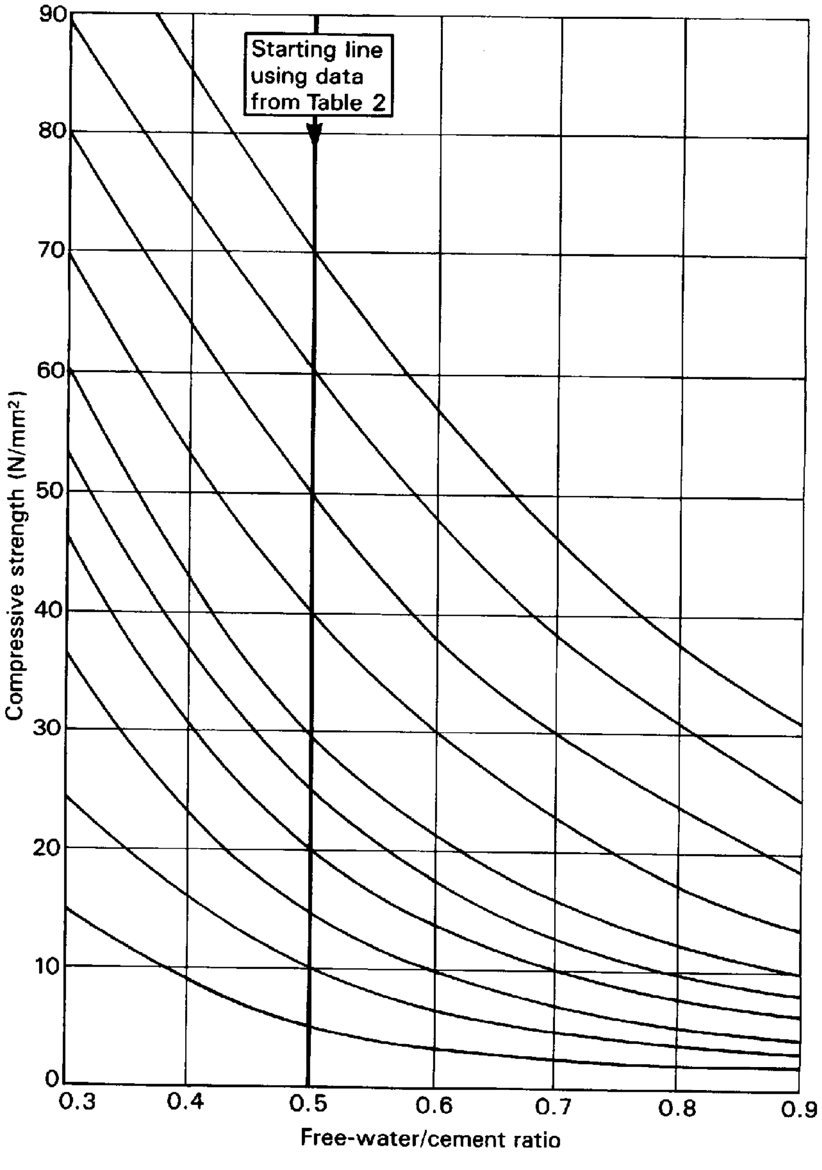

Figure 4
Relationship between compressive strength and free-water/cement ratio

Table 2 Approximate compressive strengths (N/mm^2) of concrete mixes made with a free-water/cement ratio of 0.5

Cement strength class	Type of coarse aggregate	Compressive strengths (N/mm^2)			
		Age (days)			
		3	7	28	91
42.5	Uncrushed	22	30	42	49
	Crushed	27	36	49	56
52.5	Uncrushed	29	37	48	54
	Crushed	34	43	55	61

Throughout this publication concrete strength is expressed in the units N/mm^2.
1 N/mm^2 = 1 MN/m^2 = 1 MPa. (N = newton; Pa = pascal.)

Table 3 Approximate free-water contents (kg/m^3) required to give various levels of workability

Slump (mm)		0–10	10–30	30–60	60–180
Vebe time (s)		>12	6–12	3–6	0–3
Maximum size of aggregate (mm)	Type of aggregate				
10	Uncrushed	150	180	205	225
	Crushed	180	205	230	250
20	Uncrushed	135	160	180	195
	Crushed	170	190	210	225
40	Uncrushed	115	140	160	175
	Crushed	155	175	190	205

Note: When coarse and fine aggregates of different types are used, the free-water content is estimated by the expression:

$$\tfrac{2}{3} W_f + \tfrac{1}{3} W_c$$

where W_f = free-water content appropriate to type of fine aggregate
and W_c = free-water content approporiate to type of coarse aggregate.

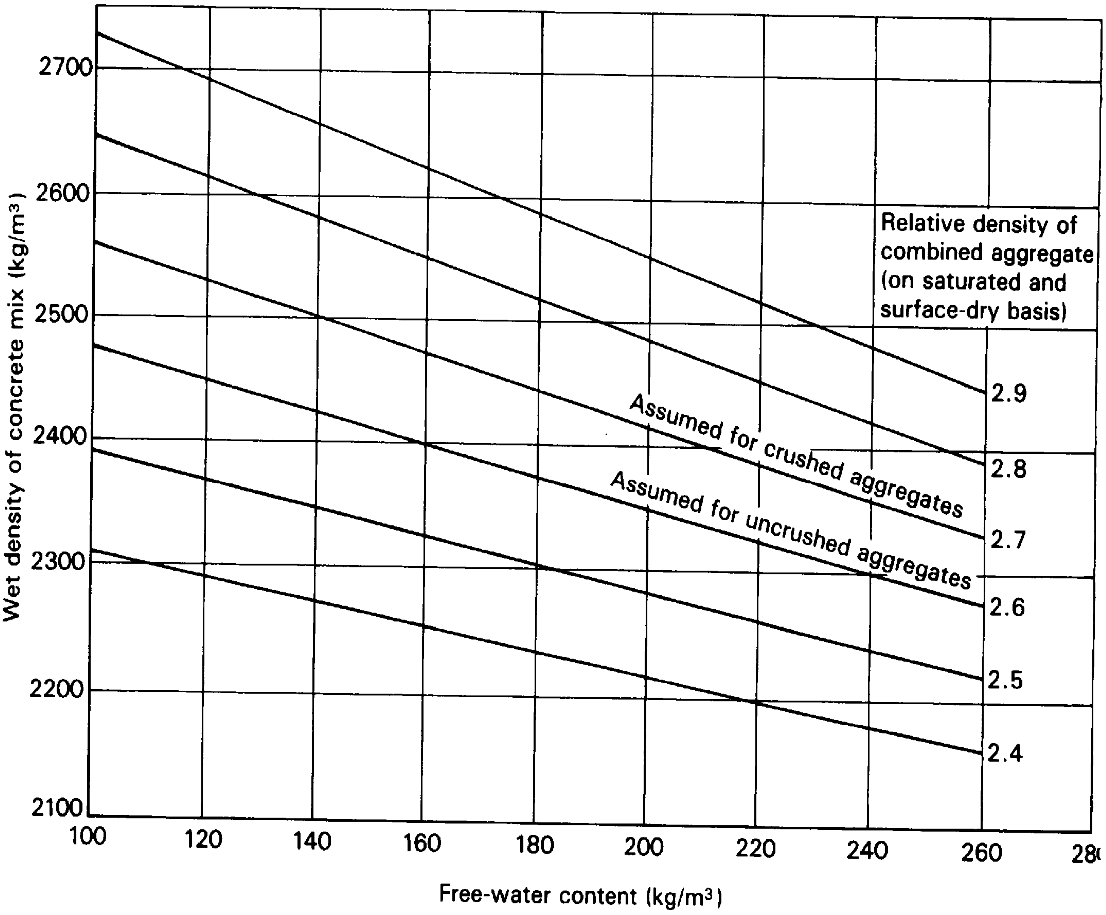

Figure 5 Estimated wet density of fully compacted concrete

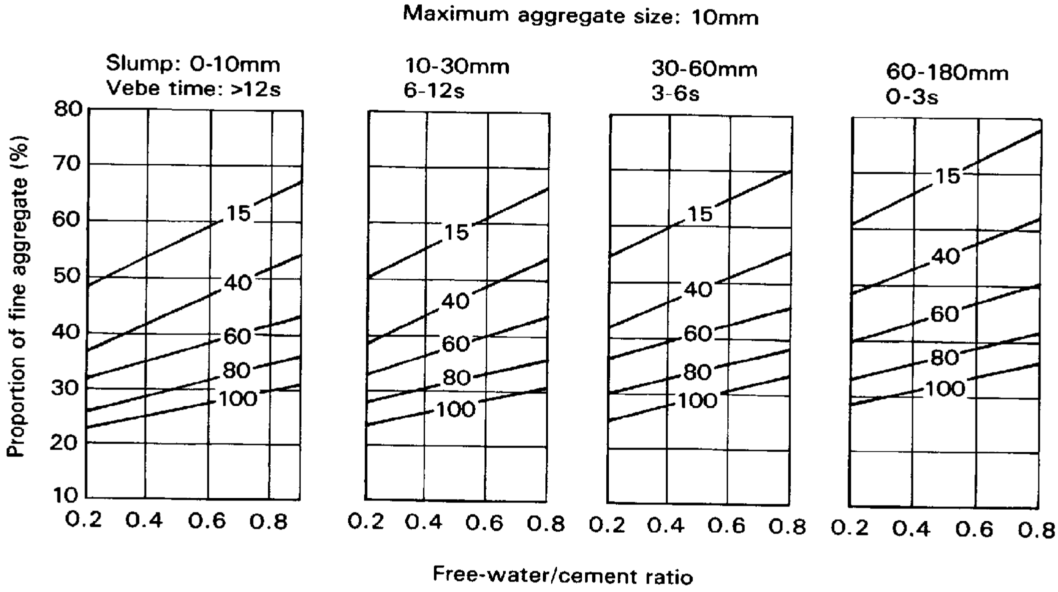

Figure 6 Recommended proportions of fine aggregate according to percentage passing a 600 μm sieve

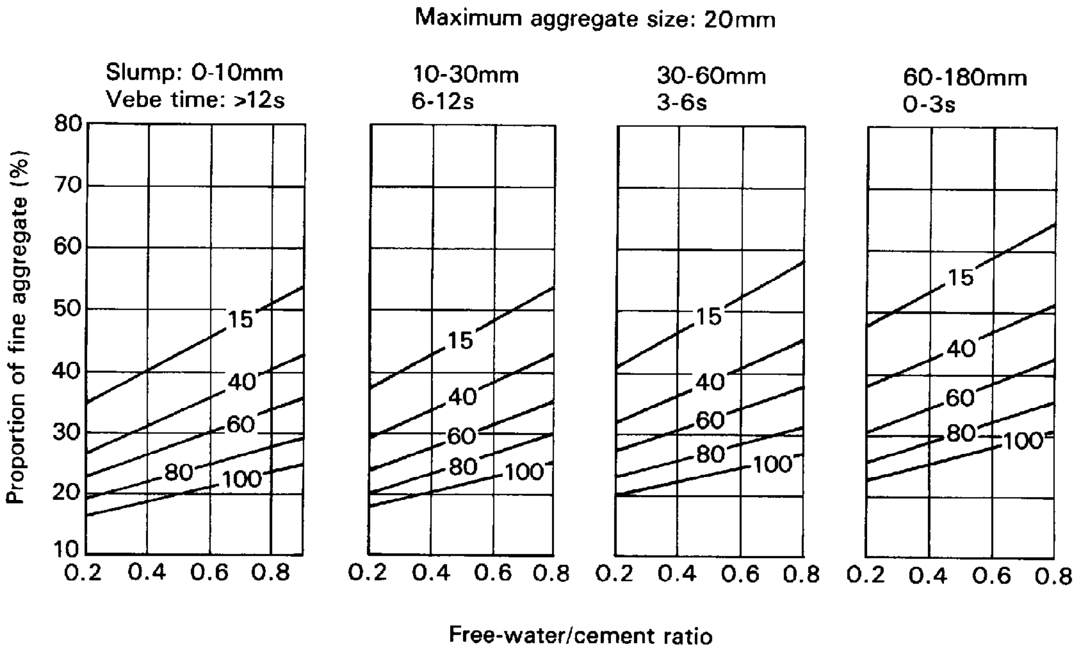

Figure 6 (continued)

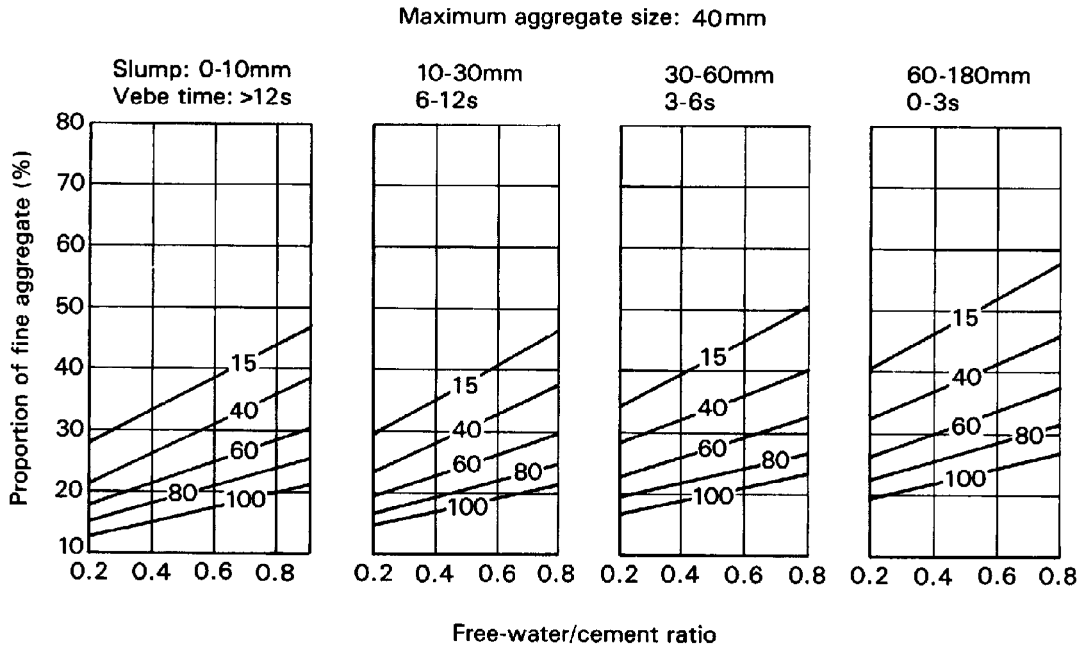

Figure 6 (continued)

B.2: Pictures

```
[21/12/16] [13:27:12] R:000
Operator  : OPERATORE1
NoTest:     00000
Test  :COMPRESSION  CH1
Sample :CUBE
a: 150.0 b:150.0  c:150.0
Area  [ mm2 ]:022500
Load      [ kN    ]:01264.2
Stress    [ MPa   ]:0056.18
Load rate [ MPa/s ]:000.000
```


0.8SP
5%
3 dayes
0.8SP
5%
3 dayes
0.8SP
5%
3 dayes