INFLUENCE OF DIFFERENT CURING CONDITIONS ON HIGH PERFORMANCE CONCRETE CONTAINING SILICA FUME

By

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ABSTRACT

This experiment is done to study of influence of different curing conditions on high performance concrete (HPC) containing silica fume. Silica fume is pozzolanic material that exhibits a considerable influence in enhancing the mechanical and durability properties of concrete. In this experiment, total of two mixes were made of Ordinary Portland Cement (OPC) as a control mix and OPC replaced with 10% silica fume as a HPC. The water to a binder ratio was kept constant at 0.44. An experimental program was performed to study the compressive strength, splitting tensile strength, change in length, modulus of elasticity, flexural strength, ultrasonic pulse velocity (UPV), water absorption, porosity, and hardened density tests. Insufficient curing can also lead to serious defects such as plastic shrinkage, cracking, and excessive drying shrinkage. These cracks increase in return permeability and decrease the compressive strength; as a result, it causes a decrease in concrete durability. Samples are curing by five methods such as immersing specimens in water, spraying specimens with water (fog room), steam curing at an ordinary pressure at 60 ^{0}C temperature for 16 hours with a delay period of 3 hours at room, cold weather curing was applied at 10 ^{0}C, and natural weather curing was applied at 28 ^{0}C as an average to cure the cube, prism and cylinder specimens until the day of testing. Test results indicate that steam cured concrete containing silica fume shows higher compressive strength at the early age but lower than immersing specimens in water and fog curing methods at 28 days. In general findings of this study suggest that Steam curing is a heat treatment method which has been used to speed up the strength development of concrete products, especially in producing precast concrete. The samples are containing silica fume should be cured by water curing to achieve well hardened properties.

ABSTRAK

Eksperimen ini dijalankan untuk mengkaji kesan perbezaan kaedah merawat sampel konkrit berkekuatan tinggi yang mengandungi *silica fume*. *Silica fume* adalah bahan *pozzolanic* yang mampu memberi impak kepada sifat-sifat mekanikal dan kekuatan sampel konkrit. Untuk penyelidikan ini, sejumlah dua adunan telah dihasilkan daripada simen biasa sebagai adunan kawalan dan 10% *silica fume* yang mana menggantikan simen biasa sebagai adunan berkekuatan tinggi. Nisbah air kepada simen adalah tetap iaitu 0.44. Kajian eksperimen telah dijalankan untuk mengkaji kekuatan mampatan (*compressive strength*), belahan tegangan (*splitting tensile*), perubahan pemanjangan (*change in length*), tahap kekenyalan (*modulus of elasticity*), lenturan (*flexural*), halaju dedenyut bunyi (UPV), keliangan dan serapan air (*porosity and water absorption*) dan ketumpatan konkrit. Kekurangan tahap rawatan kepada sampel konkrit boleh menyebabkan kecacatan seperti plastic shrinkage, keretakan (*cracking*) dan *excessive drying shrinkage*. Keretakan menyebabkan kenaikan ketelapan kembali dan pengurangan kekuatan mampatan seterusnya mengakibatkan kekuatan konkrit terjejas. Sampel dirawat oleh 5 cara seperti menengelamkan di dalam air, semburan air, rawatan stim pada tekanan biasa pada suhu 60 ^{0}C selama 16 jam dengan penangguhan selama 3 jam pada suhu bilik, suhu sejuk 10 ^{0}C dan rawatan kebiasaan pada suhu bilik 28 ^{0}C. Keputusan menunjukkan bahawa rawatan stim kepada sampel konkrit yang mengandungi *silica fume* memberi kekuatan mampatan yang tinggi pada permulaan tetapi sebaliknya berlaku kepada sampel konkrit yang dirawat di dalam air dan semburan pada usia 28 hari. Secara umumnya, penyelidikan ini mencadangkan agar rawatan stim dapat digunakan untuk mempercepatkan perkembangan kekuatan produk konkrit terutamanya di dalam

pengeluaran precast konkrit. Sampel yang mengandungi *silica fume* harus dirawat menggunakan air untuk mencapai sifat-sifat yang bagus.

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ABBREVIATIONS

BS	British Standard
HPC	High Performance Concrete
ACI	American Concrete Institute
w/c	water/cement
MPa	Mega Pascal
GPa	Giga Pascal
ISAT	Initial Surface Absorption Test
C-S-H	Calcium Silicate Hydrates
MS	Malaysian Standard
OPC	Ordinary Portland Cement
C3A	Tricalcium Aluminate
Psi	Pound/square inch
GGBS	Ground Blastfurnace Slag Cements
SF	Silica Fume
ASTM	American Society for Testing And Materials
mm	Millimeter
N/mm^2	Newton per millimeters square
ml/m^2/s	Milliliters per square meter per second
SiO2	Silicon Dioxide
Ca(OH)	Calcium Hydroxide
Kg/ m^2	kilogram per meter square
Kg/m^3	kilogram per meter cubic
UPV	Ultrasonic Pulse Velocity
CM	Controlled Mix
SSD	Saturated surface dry
>	More than
<	Less than

CHAPTER 1
INTRODUCTION

1.1 Overview

Concrete has occupied an important place among construction materials and is widely used in all types of civil engineering structures ranging from small buildings to huge ones. As a result, curing concrete structures has recently become a key issue for concrete technology, because concrete plays a critical role in building up the infrastructure system in our society and with unexpected deterioration of the existing concrete structures built in the last century, the durability of concrete structures by curing the conditions or adding some admixture materials has become a key issue for concrete technology (Nawa and Horita, 2004).

1.2 Definitions

One of the most acceptable definitions by (Neville, 1995) is stated below:
"curing is the name specified to procedures used for promoting the hydration of cement, and consists of a control of temperature and of the moisture movement from and into the concrete. More specifically, the purpose of curing is to keep concrete saturated, or as nearly saturated as possible, until the originally water-filled space in the fresh cement paste has been filled to the desired extent by the products of hydration of cement."

Curing promotes hydration by preventing moisture loss and in some cases adding moisture to the concrete, thus leading to a more dense and less permeable material. Curing enhances the ultimate compressive strength, reduces surface dusting and improves resistance to abrasion. Curing allows more water to be made available for the hydration reaction of the concrete’s cement paste which leads to better strength development. Curing problems increase when concreting in hot weather because of both higher concrete temperature and the increase in the rate of evaporation from the fresh mix. Durability, strength, and other characteristics of the concrete in hot weather critically depend on curing time and duration, whether it is immediately cured or during the first few weeks. Insufficient curing can also lead to serious defects such as plastic shrinkage, cracking, and excessive drying shrinkage (Austin et al. 1992).

The ACI 308 recommended a wet curing period of 7 days for most structural concretes and a period of 14 days for structural concretes containing supplementary cementing materials. As for membrane curing, it is also used quite regularly in the industry. This method includes the use's polyethylene sheets and curing compounds, which prevent water evaporation. In accelerated curing, it a steam curing at ordinary pressure or high pressure. This method is mainly used in precast works and cold weather (Neville, 1998). Steam curing is beneficial in terms of early strength in concrete, which is important or when additional heat is required to complete the hydration as in the case of cold weather (Cement Association of Canada, 2004). Accelerated curing reduces costs and curing time in the fabrication of precast members (Theland, 2003).

In this research four major types of curing methods used as water curing, this can be made through immersion and spraying, steam curing at an ordinary pressure at 60 ^{0}C for 16 hours, normal weather curing at 28 ^{0}C as an average and last categories in cold weather at 10 ^{0}C. These curing methods are selected as commonly used. With regard to high-performance concrete (HPC), the amount of information available for the effects of different curing conditions on the properties is limited, and the current curing concrete requirements may not be ordinary optimized for high-performance concrete. Since HPC is a relatively new class of concrete, additional research is needed to see what factors that affect the development of the physical and chemical properties.

Eventually, design codes needed to be reviewed to incorporate the necessary requirements for safe and effective use of HPC. Curing of HPC has been identified as one of the critical areas in which more information and research are needed in order to realize the full potential of this category of concrete (Carino and Clifton, 1990).

Carino and Clifton (1990) defined HPC as the concrete which has“ the required properties and consistency that not can be obtained using only traditional ingredients routinely and normal mixing, placing, and curing practices”.

HPC includes the following properties:

(1) Ease of development and compaction without segregation

(2) Enhancing the mechanical properties of long-term

(3) High strength at an early age

(4) High durability

(5) Longer life in highly environments

This is a more general definition that attempts to include a variety of the existence of concretes, which have special properties not attainable by ordinary concrete. HPC with low permeability could be achieved by using a suitable concrete mix, good construction practice and suitable curing during the early ages of hydration (Neville and Aitcin, 1998). By HPC, durability can enhance strength, resulting in long-lasting and economic structure (Leming and Ahmed, 1993). According to American Concrete Institute (ACI) “ HPC defined as concrete, which meets special performance and uniformity requirements that cannot always be achieved routinely by using only conventional materials and normal mixing, placing and curing practices”.

HPC contains the following properties (Carino and Clifton, 1990):

(1) High compressive strength, thermal capacity, acid / alkali resistance, flexibility and the best tensile properties

(2) Low permeability and shrinkage

(3) High fire resistance

(4) Excellent flow properties

(5) Good bond

HPC mixes can be designed for low permeability and to resist penetration of aggressive liquids and thus are more durable. One important subject needs to be addressed in the use of is HPC to improve the mixes and methods of curing. Changing mix proportions and admixtures that are used in concrete leads to different types of concretes to be used in different types of concrete structures.

Proportioning HPC consists of three interrelated steps (Nevile, 1995):

(1) Selecting appropriate ingredients: cement, supplementary materials, aggregates, water and chemical admixtures.
(2) Determining the relative quantities of components for the production of concrete with desired properties, strength and durability.
(3) Quality control of every stage of the process of making concrete.

Low permeability concretes are produced by improving the properties of a matrix by reducing water to the binder ratio (0.45 and less) and by adding pozzolanic material such as silica fume to be used as a cementation material which changes the microstructure of the concrete (Neville and Aiticin, 1998). These modifications to the mixes results in higher compressive strength than conventional concrete, above 41 Mpa (6,000 psi).

1.3 Mineral Admixtures

Silica fume (SF) is probably the most common addition to the concrete mixtures to produce HPC. This material is also called reduced silica fume or microsilica, and is a finely powdered silica that is amorphous to very pozzolanic development of the properties in the presence of water and calcium hydroxide.

Silica fume (SF) can be defined as material who " is a by-product from electric arc furnaces used in the production of Ferro-silicon alloys and silicon metal. Silica fume (SF) consists of fine particles with a surface area (20,000 m^2/kg). It is a very reactive pozzolan which is suitable to be used in cement and concrete industries, particularly in the production of high strength and high performance concretes (HPC)" (Tam, 1998).

SF additives are added to the mixture of concrete mixes to improve the properties of concrete; there are different colors of silica fume; the most famous ones are white and gray as shown in the figure 1.1 below.

Figure 1.1 :Silica Fume Colors

There are two methods of using silica fume in concrete:

(1) As a partial replacement of cement to decrease the cement content

(2) As an addition to improve the concrete properties for both in fresh and hardened concrete.

Adding SF also increases the strength and reduces the permeability of the concrete to chloride ions, which protects the reinforcing steel of concrete from corrosion. The optimum dosage of SF for general construction varies between 7 and 10%, but in special cases it is up to 15%. In the previous decade, considerable attention has been paid to the use of silica fume as a partial replacement of cement to produce high-strength concrete (Silica Fume User Manual, 2005).

1.4 Problem Statement

The addition of SF could enhance the strength and durability related properties of concrete. However, there are other factors that will influence the strength and durability properties of concrete mix containing SF. One of the factors is the curing method. Curing is very important in order to continue the hydration process because it helps to increase the compressive strength of the concrete. Since the hydration of cement may take time, days, weeks, or even months, curing must be undertaken for a duration of time for the concrete to achieve its potential strength and durability.

Insufficient curing can lead to serious defects such as plastic shrinkage, cracking, and excessive drying shrinkage. These cracks increase in return permeability and decrease the compressive strength; as a result, it causes a decrease in concrete durability. There are several curing methods that can be used such as normal water curing, steam curing and even exposed curing. Each method has its own effects on the properties of the concrete. Temperature control is an important factor in curing as it will affect the rate of cement hydration. Steam curing of concrete at atmospheric pressure is a technique used to obtain high early strength values. Accordingly, different types of curing will be compared. The findings of this research should enhance our understanding of the effects of appropriate curing method on strength and durability properties of high performance concrete containing SF.

1.5 Objectives

The main objectives of this study are listed below.

(1) To determine the mechanical properties of high performance concrete under different curing conditions.

(2) To determine appropriate curing conditions of high performance concrete.

1.6 Scope of study

The scope of this study is to investigate the influnce of different curing conditions on high performance concrete containing silica fume will affect its strength and durability properties. The experiment starts with the preparation of related equipments and materials. A control mix is first produced followed by the production of a concrete mix containing the SF. The mix is produced by following the specified mix proportions and concrete grade. The mixes are cast in appropriate moulds. In this research five major types of curing methods will be used as, immersing specimens in water, spraying specimens with water (fog room), normal weather curing at 28 ^{0}C as an average, cold weather at 10 ^{0}C and steam curing. Before the mixes are steam cured, the mixes are allowed to settle for 3 hours. This is known as the delay period, which usually ranges from 2 to 5 hours. After the delay period, the concrete still in moulds will be put in the steam curing tank for 16 hours at 60 °C. This is the optimum curing period and temperature. After 8 hours, the concrete mixes are cooled down for 5 hours before demoulding process and keeping the samples in a water until the testing days of 1,7 ,14 and 28 days.

1.7 Research Layout

The study consists of five chapters

(1) Chapter One presents the introduction (which provides the overview, definition of key, mineral admixtures, objectives, scope of study, and research layout)

(2) Chapter Two reviews the literature of previous research on the influence of curing conditions and HPC.

(3) Chapter Three includes the details of the materials used in this study such as mix proportion, mixing, preparation of test specimens, curing and experimental test.

(4) Chapter Four presents the results of experimental work and discussion.

(5) Chapter Five provides the conclusions which are drawn from the results of this.research; it also provides some recommendations for further research work.

CHAPTER 2

Literature Review

2.1 Introduction

This chapter discusses research related to the process of curing of concrete. It also presents a general summary accompanied with conclusions not only on the effects of curing methods but also on the testing methods used to assess curing efficiency, particularly, the efficiency of curing compounds. Besides, it discusses research related to high-performance concrete, materials, and to supplementary cementing materials.

2.2 Curing

There are numerous definitions of curing with respect to concrete technology; however, most of these definitions deal with the basic principles and requirements that are similar in many respects. Some of these definitions are including the following: ACI Committee 116 (1990) defines curing as “the maintenance of a satisfactory moisture content and temperature in concrete during its early stages so that the desired properties may develop”. ASTM Committee C9 (ASTM C 125, 1998) “the maintenance of moisture and temperature conditions in a cementitious mixture to allow its properties to develop”. Neville (1995) states that curing is the name given to procedures used for promoting the hydration of cement, and consists of a control of temperature and of the moisture movement from and into the concrete. More specifically, the objective of curing is to keep concrete saturated, or as nearly saturated as possible, until the originally water-filled space in the fresh cement paste has been filled to the desired extent by the products of hydration of cement.

Neville and Aitcin (1998), conducted the reseans of curing concrete in its early life are due to the following:

(1) To reduce plastic shrinkage.

(2) To ensure passable surface strength.

(3) To ensure passable surface zone durability.

(4) To protect it from freezing.

(5) To protect it from harmful vibration, impact or damage.

Concrete properties are significantly influenced by curing since it greatly affects the hydration of cement. Usually, the hydration of cement practically stops when the relative humidity inside the capillaries is about 0.8 of the saturation pressure **(**Neville, 1995). This also conforms to the research from (Zain and Matsufuji, 1997) that early drying of concrete may stop the cement hydration before the pores are blocked by hydration products and thus, a more continuous pore structure might be formed. Practices and appropriate cure are often poorly or unimportant in real life applications. If a site cure of concrete is stopped after taling along period of time, hydration possibly takes place (Neville, 1998). Accordingly, early drying of concrete may stop the cement hydration before the pores are decreased by hydration; for that reason, a more continuous pore structure may be formed. The concrete cover is more sensitive to drying since it is more prone to lose water. The curing condition and temperature also affect the curing properties of hardening concrete. If curing is neglected in the early age of hydration, the compressive strength, flexural strength, and modulus of elasticity of concrete will decrease at later ages causing by this an irreparable loss (Aitcin et al., 1994). Klieger (1998) adds that high temperature curing delay the hydration from the cement in the later ages and forms an open pore structure of cement paste. This will consequently, affect the properties of hardened concrete. Houssam and Ziad (1999) conducted a study to assess the effect of curing procedures on properties of silica fume concrete. The basic principle of this study was three different curing methods were used steam curing, moist curing, and air curing. Mechanical properties such as compressive strength, flexural strength, permeability, and permeable voids were determined. Steam curing method was found to improve the properties of silica fume concrete, while air curing exhibited unfavorable effects as compared to moist curing. The results indicated that moist curing, steam curing decreased permeability of silica fume concrete while air curing increased permeability. The change of permeability caused by curing is dependent on the silica fume content of the concrete mix. However, concrete with 30% silica fume content exposed to air curing experienced a significant increase in permeability. This is attributed to the extensive shrinkage and thus cracking, which develops due to air curing.

Kern et al. (1995) conducted a study to assess the effectiveness of different curing methods. The basic principle of this study was to state the degree of hydration that determines to a great extent the durability of concrete, and the degree of hydration that determines the amount of chemically bound water. According to them, curing is the efficiency and the ability to keep water in the concrete to ensure high quantities of chemically-bound water and to ensure a high degree of hydration. They also added that early drying can increase shrinkage and cracking, which may in return increase the durability problems of concrete.

Safiuddin et al. (2007) studied the effect of different curing methods on the properties of microsilica concrete. Three curing methods were used such as water curing, wrapped curing, and dry air curing was applied at 20±2 ^{0}C to cure the cylinder and cube specimens until the day of testing. The cylinder specimens were tested to determine the compressive strength, spliting tensile, dynamic modulus of elasticity, ultrasonic pulse velocity, and rate of moisture movement of microsilica concrete. Furthermore, the cube specimens were tested to determine the initial surface absorption of the concrete and hardened density. These authors found that water curing as well as wrapped curing provided much better results than dry-air curing. The results have shown that the rate of moisture movement was significant when the specimens were subjected to dry-air curing. It hindered the hydration process, and thus affected the compressive strength and other properties of the concrete. Finally, the overall findings of this study suggested that concrete contain silica fume should be cured by water curing to achieve well hardened properties.

Ramezanianpour and Malhotra (1995) and Safiuddin et al. (2000) conducted their study in this respect to find that strength of concretes containing fly ash or silica fume appears to be more sensitive to poor curing compared to the control concrete. They added that if a concrete is not well cured particularly at the early age, it is not gain the properties and durability at the desired level due to a lower degree of hydration. Consequently, it is not be in conformity with the standard specifications.

Khan and Ayers (1995) conducted their study to determine the minimum durations of curing for silica-fume (SF) concretes for achieving a given level of strength development. They compared the minimum duration at 23 ^{0}C for SF and used four concentrations of SF concrete mixtures (5,10,15,and 20)% with a plain portland cement concrete with 10 % SF to be miniumumly cured for 3 days at 23 ^{0}C.

2. 3 High-Performance Concrete (HPC)

There are numerous definitions of HPC technology, the following is cases in point: The American Concrete Institute (ACI) defined HPC as a material which meets special performance and uniformity requirements that cannot always be achieved by using conventional materials, normal mixing, placing and curing practices. Civil Engineering Research Foundation (CERP) stated that in high performance construction materials and systems, America uses a basic program for its infrastructure. HPC is a concrete material that is merited by the following properties:

(a) Ease of placement.

(b) Long-term mechanical properties.

(c) Early age strength.

(d) Durability.

(e) Volume stability.

(F) Extended service life in severe environments.

Concrete has since a long time been a main material for providing a stable and reliable infrastructure. The concrete with compressive strength of 20-40 N/mm^2 was traditionally used in construction projects. However, demanding more complex structural forms along with the deterioration and the long-term poor performance of conventional concrete, research on developing concrete materials was accelerated.

The main difference between conventional concrete and HPC lies in the essential use of chemical and mineral admixtures. Using a combination of chemicals reduces the water content, which in return reduces the porosity of wet cement in the past**.** Moreover, the mineral admixture is generally industrial by-products; their use can provide basic economic benefits. Malhotra (1999) reported that the use of superplasticezer and mineral admixtures helps replacing the concrete economic strength by the improved HPC**.** Figure 2.1 shows the factors which influence HPC:

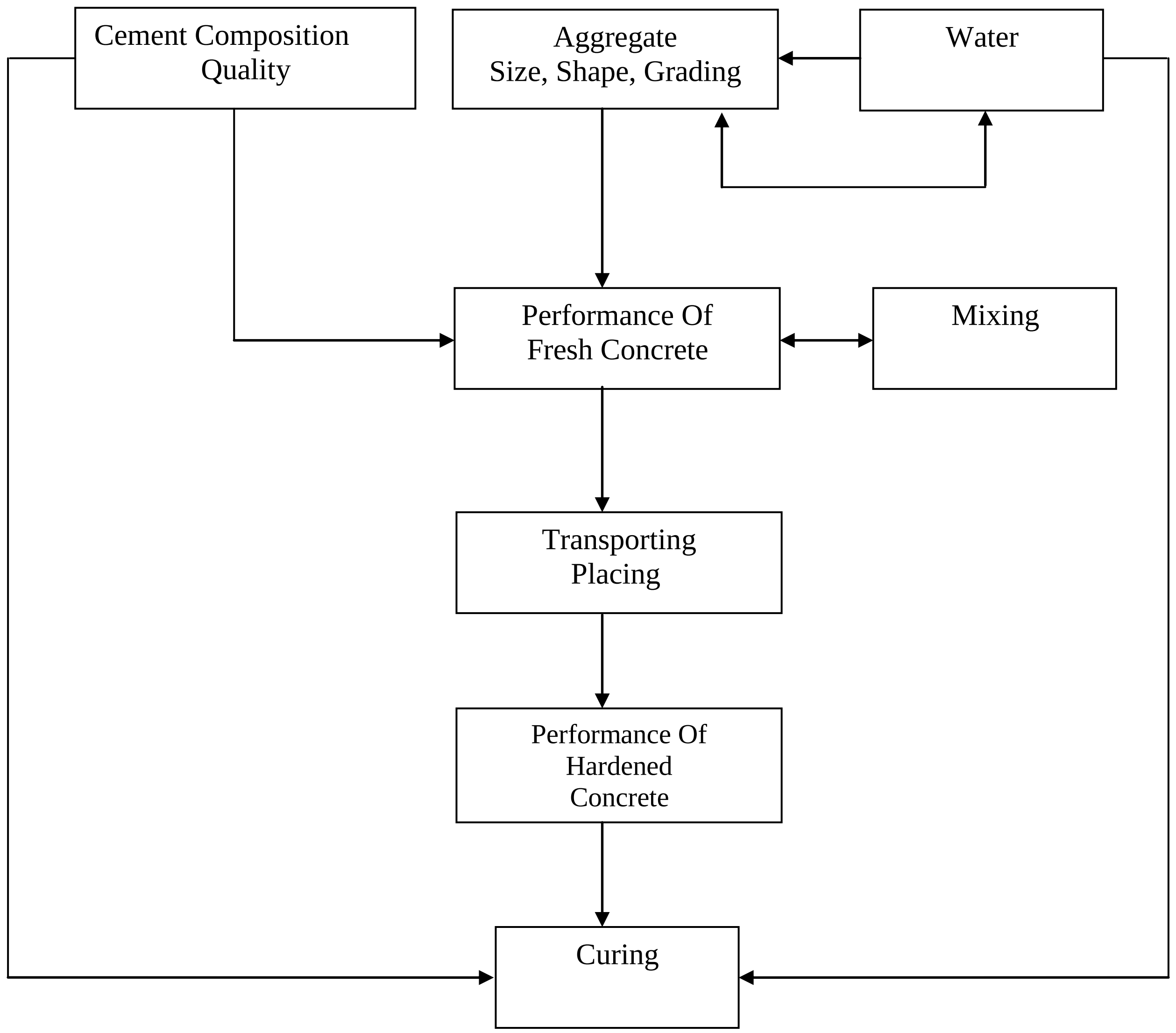

Figure 2.1: Factors Influencing HPC

2.4 Applications of HPC

The economic benefits of using high strength was known for many years as HPC in the columns of high-rise buildings. In simple terms, high strength concrete provides the most economical way to withstand a vertical load on a building foundation. There are three main components that contribute to the cost of the column; they include: reinforcing steel, concrete, and formwork. Though the use of HPC reduces the size of the column, there is a need for less formwork and less concrete. At the same time, the amount of vertical reinforcements can be reduced to the minimum by the code. The net result is to achieve lower cost with a smaller column size, a least amount of reinforcement and with the highest concrete strength (Henry, 1999). In order to achieve high strength for HPC, various important factors that control the strength of concrete must be understood, such as:

(1) The properties of cement paste.

(2) The properties of aggregate.

(3) The various chemical and mineral admixtures that are used.

(4) Mixing, compacting and curing.

(5) Testing procedures.

All these factors required to be optimized in order to get a concrete material with very high compressive strength. Thus, it is necessary to look carefully at cement fineness and other chemical properties when selecting cement for use in HPC.

Bashah (2006) reported that an increase in the fineness of the portland cement usually increases in the early strength of concrete. This is due to the connection of a higher surface area with water concrete; a matter that leads to have a more rapid hydration. Further, it is generally assumed that the compressive strengths are between 40 to 80 Mpa (6000 psi to 12000 psi), and that any normal weight aggregate can be used. The design that mixes concrete is mainly based on the water-cement ratio. Most of the past studies have suggested that the water-binder ratio of

HPC needs to be much lower than that of ordinary concrete. While ordinary concrete has a water-binder ratio of 0.50 and higher, generally water-binder ratio of HPC below 0.35 (Aitcin, 1994).

Safiuddin et al. (2000) studied the possibility of developing HPC using SF at relatively high water-binder ratios. For this purpose, water-binder ratios of 0.45 were considered. Test specimens were air and water cured and exposed to an average temperature range of 20 °C to 50 °C. The compressive strength, initial surface absorption (ISA), and modulus of elasticity of hardened concrete was determined in the laboratory. These authors found that concrete under water curing methods the best results. The highest level of modulus of elasticity and compressive strength and the lowest level of ISA were produced by SF concrete under water curing method and at a temperature of 35°C. Furthermore, test results indicated that, under controlled curing conditions. It is possible to produce HPC at relatively high water-binder ratios.

2.5 Significant of High Strength Concrete and Silica Fume

The significant of using high strength concrete often balance the increase in material cost. The following are some advantages that can be accomplished (Nawy, 1996):

(1) Reduction in member size, resulting in an increase in rentable space and reduction in the volume of produced concrete with the accompanying saving in construction time.

(2) Superior long-term service performance under static, dynamic, and fatigue loading.

(3) Low creep and shrinkage.

(4) Greater stiffness as a result of a higher modulus of elasticity.

Gonen and Yazicioglu (2009), investigated the silica fume (SF) used in this technology has three main function:

(a) Filling the voids between the large class particles (cement).

(b) Increasing the resistance of concrete to acid and sulfate attacks. Besides, it improves the durability of concrete by reducing porosity and the permeability of a cement paste matrix.

(c) Producing secondary hydrates by a pozzolanic reaction with the lime resulting from the primary hydration. Moreover, it makes the concrete more resistant to abrasive forces, and reduces as well the expansion generated by alkali-aggregate expansion.

2.6 General High-Performance Concrete (HPC) Materials

The component of HPC material proportions were determined in part depending on the process of optimizing the rough mixture. This method allows producing a finely graded and highly homogeneous concrete matrix. Bickley et al. (2001) reported that when constructing bridges, 40MPa (6,000 psi) of HPC could be economically made while meeting durability factors of air-void system and resistance to chloride penetration. Table 2.1 lists materials that are often used in HPC; in addition to the reason behind selecting them.

Table 2 .1: Materials Used in High-Performance Concrete (HPC)
Bickley et al. (2001)

Material	Primary Contribution/Desired Property
Portland cement	Cementing material/durability
Blended cement	Cementing material/durability/high strength
Fly ash	Cementing material/durability/high strength
Slag	Cementing material/durability/high strength
Silica fume	Cementing material/durability/high strength
Calcined clay	Cementing material/durability/high strength
Metakaolin	Cementing material/durability/high strength
Calcined shale	Cementing material/durability/high strength
Superplasticizers	Flowability
High-range water reducers	Reduce water to cement ratio
Hydration control admixtures	Control setting
Retarders	Control setting
Accelerators	Accelerate setting
Corrosion inhibitors	Control steel corrosion
Water reducers	Reduce cement and water content
Shrinkage reducers	Reduce shrinkage
ASR inhibitors	Control alkali-silica reactivity
Polymer/latex modifiers	Durability
Optimally graded aggregate	Improve workability and reduce paste demand

2.6.1 Silica Fume (SF)

Silica fume (SF) is: A by-product of silicon metal or silicon-alloy metal factories. Although the silica fume was a waste of industrial materials, it became the most valuable by-product between the pozzolanic materials due to its very active and high pozzolanic property. Currently, it is widely used in concrete or cement as an admixture (Turkmen, 2003). Ktftng and Odd (1995) reported that concrete materials that contain silica fume have a higher resistance to water penetration in comparison to concrete materials with no silica fume. The reason behind adding SF is due to changes in the microstructure of the concrete. These changes consequences from two different but equally important processes. The first for this is the physical aspect of SF, and the second is the chemical contribution. The physical phase of this action enhances the void system of cement paste; particularly, the transition zone. Results of this work form of SF provide significant improvements in the compressive strength, flexural strengths; in addition to other significant improvements in durability and impermeability (Pigeon and Plante, 1989).

Turkmen (2003) reported that the slumps of the concrete increased with increasing water–binder ratio and decreased by use of BFS and SF mineral admixtures. So, an acceptable slump value is 30-60 mm in high strength concrete. In addition, the dry unit weight of the concretes decreases with increasing water–binder ratio and when using 10% of SF instead of ordinary portland cement (OPC) increases the compressive strength, durability and mechanical properties of the specimens. Bhanja and Sengupta (2004) further reported that the influence of SF on the tensile strength of concrete and on the optimum percentages of SF replacement for tensile strengths have been found to be a function of w/c ratio of the mix. The optimum 28-day split tensile strength has been obtained from a range of 5–10% SF replacement level, whereas the value for flexural strength ranged from 15% to 25%.

El-Korchi and Toutanji (1995) reported that the morter that contains SF as a partial replacement for cement has its compressive strength increased. Furthermore, it was fond that SF improves strengthening the bond between the cement paste and the aggregate. They also added that the partial replacement of cement by SF and the addition of super plasticizer will increase the strength of mortar. In this regard, (Persson, 1996) commented that the degree of hydration of chemically bound water content, reported that when the concrete does not contain SF, the degree of water constantly increases, but when it contained SF, the degree of water decreases after approximately 90 days.

2.6.2 Superplastizer/High Range Water Reducers

Superplasticizers are chemical admixtures that can be added to concrete mixtures to improve workability. In order to produce stronger concrete, less water is added. This makes the concrete mixture very unworkable and difficult to be mixed; necessitating, accordingly, the use of plasticizers and superplasticizers. Superplasticizer or high range water reducers is admixtures that allow a large water reduction or greater flow ability without slowing the set time or increasing air entrainment.

Ramachandran (1984) stated that the advantages derived from the use of superplasticizer include the following:

(1) The production of concrete that has a high workability for easy placement.

(2) The production of HPC with normal workability, but with lower water content.

(3) A mix, which has a combination of better than normal workability and lower than the normal amount of water or, which is with less cement but has a normal strength and workability.

Aignesberger and Kern (1981) investigated the effect of superplasticizer on the compressive strength of concrete. The results showed that the addition of 3% of superplasticizer increases the compressive strength from 80 to 150% at 24 hours and from 25 to 80% at 28 days. The results showed that water reduction in up to 30 percent is possible when using melamine-based superplasticizer and maintains equal workability to the reference mix. However, it was found that there is no exact method for determining the required superplasticizer dosage. Accordingly, trial and error method was used in this purpose, despite that there have been some studies done to determine the required superplasticizer dosage. Jerath and Yamane (1987) studied the relationship between compressive strength and the mechanical properties of superplasticizer concrete with w/c ratios of 0.28, 0.35, 0.45, and 0.55. In this study, they used ordinary portland cement type, I (362-565 kg/m^3) to determine the effect of different dosages of high molecular weight sulfonated naphthalene condensated superplasticizer on the compressive strength, stress-strain relationship, modulus of an elasticity, poisson ratio, modulus of rupture, and the split cylinder tensile strength of normal, medium and high-strength concrete mixes.