UNIVERSITY OF GAZİANTEP
GRADUATE SCHOOL OF
NATURAL & APPLIED SCIENCES

EFFECT OF VOLCANIC PUMICE POWDER ON PROPERTIES OF PLAIN AND SILICA FUME BASED SELF COMPACTING CONCRETES

M. Sc. THESIS
IN
CIVIL ENGINEERING

BY
SAAD ABDULRAZZAK MUKHLIF

JANUARY 2013

Effect of volcanic pumice powder on properties of plain and silica fume based self compacting concretes

M.Sc. Thesis
In
Civil Engineering
University of Gaziantep

Supervisor

Assoc. Prof. Dr. Erhan GÜNEYİSİ

By
Saad Abdulrazzak MUKHLIF
January 2013

T.C.
UNIVERSITY OF GAZİANTEP
GRADUATE SCHOOL OF
NATURAL & APPLIED SCIENCES
CIVIL ENGINEERING DEPARTMENT

Name of the thesis : Effect of volcanic pumice powder on properties of plain and silica fume based self compacting concretes

Name of the student : Saad Abdulrazzak MUKHLIF

Exam date : 28.01.2013

Approval of the Graduate School of Natural and Applied Sciences

Assoc. Prof. Dr. Metin BEDIR
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

Prof. Dr. Mustafa GÜNAL
Head of Department

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

Assoc. Prof. Dr. Erhan GÜNEYİSİ
Supervisor

Examining Committee Members Signature

Assoc. Prof. Dr. Erhan GÜNEYİSİ ____________

Assoc. Prof. Dr. Mehmet GESOĞLU ____________

Assist. Prof. Dr. M. Akif KÜTÜK ____________

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Saad MUKHLIF

ABSTRACT

Effect of volcanic pumice powder on properties of plain and silica fume based self compacting concretes

Mukhlif, Saad Abdulrazzak
M.Sc. in Civil Engineering
Supervisor: Assoc. Prof. Dr. Erhan Güneyisi
January 2013, 83 pages

In this thesis, an experimental study conducted on the effects of volcanic pumice powder (VP) on the fresh and hardened properties of self compacting concretes (SCCs) with and without silica fume (SF) was investigated. In the first group, SCCs without SF were produced with 0%, 5%, 10%, and 20% replacement levels of VP. However, for the second group, SF incorporation was achieved by a constant SF replacement level of 8%. The investigated fresh properties of the concretes were slump flow diameter, $T_{500\ mm}$ slump flow time, V-funnel flow time, and L-box height ratio. The hardened properties, on the other hand, were compressive strength development, gas permeability, water absorption, water sorptivity and rapid chloride permeability. The tests on the hardened properties of concretes were carried out at the end of 28 and 90 days of water curing. Moreover, statistical study, namely general linear model analysis of variance (GLM-ANOVA), was performed in order to see the significance of the critical parameters such as inclusion of SF and replacement level of VP on the properties of SCCs. The use of volcanic pumice powder resulted in increase in fluidity of SCCs in fresh state while SF increased the viscosity. The results have also revealed that SF incorporation compensated the deterioration of hardened properties of concretes due to increasing amounts of VP, at varying magnitudes.

Keywords: Fresh properties, Hardened characteristics, Self compacting concrete, Silica fume, Volcanic pumice powder.

ÖZ

Volkanik pomza tozunun yalın ve silis dumanı kendiliğinden yerleşen betonların özelliklerine etkisi

Mukhlif, Saad Abdulrazzak
İnşaat Mühendisliği, Yüksek lisans tezi
Danışman: Doç. Dr. Erhan Güneyisi
Ocak 2013, 83 sayfa

Bu tez çalışmasında volkanik pomza tozunun (VP) silis dumanı (SD) içeren ve içermeyen kendiliğinden yerleşen betonların (KYB) taze ve sertleşmiş özellikleri üzerindeki etkilerini incelemek amacıyla deneysel bir çalışma yapılmıştır. İlk grup KYB'lar VP'nun çimentoyla ağırlıkça %0, %5, %10 ve %20 oranlarında yer değiştirmeleriyle elde edilmiştir. Daha sonra silis dumanının %8 oranında katılmasıyla ikinci grup KYB'lar üretilmiştir. İncelenen taze özellikler; yayılma çapı, yayılma süresi, V hunisi akış süresi ve L kutusu yükseklik oranı iken, sertleşmiş özellik olarak basınç dayanımı gelişimi, gaz geçirimliliği, su emme, kılcal su geçirimliliği ve hızlı klorür geçirimliliği deneyleri gerçekleştirilmiştir. KYB'ların sertleşmiş özellikleri 28 ve 90 günlük kür süreleri sonunda test edilmiştir. Bunun yanı sıra genelleştirilmiş doğrusal model varyans analizi kullanılarak VP değişim düzeyi, SD ilavesi gibi faktörlerin istatistiksel anlamlılıkları irdelenmiştir. Elde edilen sonuçlara göre VP miktarının artması KYB'ların akışkanlığını artırırken, SD ilavesi viskoziteyi artırıcı etki göstermiştir. Ayrıca, SD ilavesinin, KYB'ların sertleşmiş özelliklerinde VP kullanımından kaynaklanan olumsuz etkiyi telafi ettiği görülmüştür.

Anahtar Kelimeler: Taze özellikler, Sertleşmiş özellikler, Kendiliğinden yerleşen beton, Silis dumanı, Volkanik pomza tozu.

To My Family, they should receive my greatest appreciation for their enormous love. They always respect what I want to do also give me their full support encouragement over the years.

ACKNOWLEDGEMENTS

First praise is to **ALLAH**, the Almighty, on whom ultimately we depend for sustenance and guidance. I am ever grateful to God, the Creator, and to whom I owe my very existence. My sincere appreciation goes to my supervisor Assoc. Prof. Dr. **ERHAN GÜNEYİSİ**, whose guidance, careful reading and creative comments was valuable. His timely and efficient contribution helped me shape this into its final form and I express my sincerest appreciation for his assistance in any way that I may have asked.

I don’t forget to thank Assoc. Prof. Dr. **MEHMET GESOĞLU** and Assist. Prof. Dr. **M. AKİF KÜTÜK**; for his encouraging, supporting.

A special thank to University of Gaziantep for the real support and laboratory facilities. Special thank to Research Asst. **KASIM MERMERDAŞ** and I never forget his creative remarks, optimism messages and unrequited knowledge presented me during the experimental work. And those who were directly or indirectly involved in the process of producing this research report, for their generous assistance, and to all my friends, for their support and giving me a suitable environment to study.

I would like to express my deep appreciation to my **mother** and my **father** God's mercy and my **wife** and **brother**, to whom I dedicate my work. I am thankful for their love and best wishes, which despite of their physical absence has helped me in the successful completion of my study.

TABLE OF CONTENT

CHAPTER 4: TEST RESULT AND DISCUSSIONS..

LIST OF FIGURES

`

LIST OF TABLES

TABLE **Page**

LIST OF SYMBOLS/ ABREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ACI	American concrete institute
ASTM	American standard for testing materials
BC	Blended cement
DS	Drying shrinkage
EFNARC	European Federation for Specialist Construction Chemicals and Concrete
FA	Fly ash
GGBFS	Ground granulated blast-furnace slag
GHG	Green house gases
HPC	High performance concrete
Ka	Gas permeability coefficient
PC	Ordinary Portland cement
PVPC	Portland volcanic pumice cement
PFAC	Portland fly ash cement
PVAC	Portland volcanic ash cement
RCPT	Rapid chloride permeability test
SCC	Self-compacting concrete
SCMs	Supplementary cementing materials
SF	Silica fume

SP	Superplasticizer
VA	Volcanic ash
VP	Volcanic pumice powder
VPC	Volcanic pumice concrete
WBCSD	The world business council for sustainable development
w/c	Water/cement ratio
w/b	Water/binder ratio
w/cm	Water /cementitious material ratio

CHAPTER 1

1. INTRODUCTION

1.1. General

From the time when self compacted concretes (SCC) were introduced to the industry of the construction in the last two decades, much of the extensive research and development work has of necessity been afraid with the achievement and assessment of fresh and hardened properties (Demone, 2007). The SCC is a new type of concrete with high capacity resistance to segregation and excellent deformability. It also can flow among high reinforcement steel and small area and corners of moulds without any compacted with mechanical vibrato during the placing process (Okamura, 1997; Okamura et al., 1993). Also decreases the noise level on the construction site, and increases productivity. Use of SCC, thus improve both the conditions for the labour on the work site and for the surroundings (Persson, 2001).

A medium viscosity resists segregation, bleeding, and keeps its uniformity through transportation, placing and curing to certify sufficient structural performance and long-term durability (Holton, 2004; Sonebi, 2004). For SCCs, in order to achieve high mobility, it's commonly necessary to use superplasticizer. In case of addition large amount of Portland cement (PC), viscosity modifying admixture is used to eradicate segregation (Nagamoto and Ozava, 1997; Okamura and Onchi, 1999).

Usages of high volume of PC and chemical admixtures increased the cost of SCCs remarkably (Sari et al., 1999; Sakata et al., 1996; Lachemi et al., 2004; Saric-Coric et al., 2003). However, using mineral admixtures like fly ash, silica fume, volcanic ash, furnace slag, and limestone filler, etc, could decrease material cost of SCC and also enhance concrete's fresh and hardened properties (Erdoğan, 1997).

The perception has been developed for this research study after following all the general purpose of testing new sustainable production processes, as these involved by the SCCs, in the construction field, in order not only to save natural raw materials and reducing energy consumption, but also to recycle industrial by-products. Blast furnaces represent the main steel-making processes used in the iron metallurgy, approximately 600000 tones of grand granulated blast furnace slag (GGBFS) is generated annually in Turkey by steelmaking processes (Bilgen et al., 2010).

Also, the aggregates affect on the mechanical and durability performance of SCCs as inhabited 60% of SCC volume, aggregates have an essential effect on SCC characteristic properties (Su et al., 2001).

Using mineral admixtures especially in SCC necessitates further attention. On incorporation of such materials, certain properties of the concretes may be enhanced whereas others may worsen relative to the plain Portland cement concrete. Previous investigations show that the uses of mineral admixtures in concrete production improve the durability of concretes. For example silica fume and metakaolin increase substantially early concrete strength but imparts sharp fall in workability to fresh concrete (FIP Commission, 1988). While fly ash decreases early strength, retards setting time but improves workability (Cabrera, 1986). Park et al. (2005) also, investigated the influence of the cementitious materials containing fine particles on the rheology of the pastes. They reported that the rheological characteristics of the pastes were greatly affected by the incorporation of fine materials.

1.2. Research Objectives

The objectives of this thesis can be listed as investigating the effects of volcanic pumice powder on the fresh, mechanical, and durability properties of plain and silica fume based self compacting concrete.

Thereafter, the volcanic pumice powder (VP) and silica fume (SF) replaces the Portland cement within the self-compacting concrete at different replacement levels to monitor the effects on properties of self-compacting concretes. Experimentally, eight SCCs mixtures were prepared with water-binder ratio of 0.37 and a total binder content of 520 kg/m^3. The selected level of replacement for VP was 5, 10, and 20 percent of the Portland cement (PC) while that for SF was 8 percent of PC. Fresh properties of SCCs were observed through slump flow time and flow diameter, V-funnel flow time, and L-box height ratio. Hardened properties were evaluated in terms of compressive strength, chloride ion permeability, sorptivity index, water absorption, and gas permeability.

1.3 Thesis Organization

This thesis consists of five chapters. Chapter 2 presents a literature review and general background information about SCC. Workability requirements and material behaviors are also explained. Also, this chapter explains the mineral admixture such as volcanic pumice, silica fume and its effect on the fresh, mechanical, and durability properties of SCCs.

Chapter 3 covers the experimental program conducted throughout this study. Properties of cement, aggregates, mineral and chemical admixtures used in the concrete production as well as the tests on fresh and hardened properties of SCCs are included.

Chapter 4 provides the test results of the experiments conducted in this task. Furthermore, how the self-compacting concrete made with volcanic pumice powder and silica fume affect the fresh, mechanical, and durability features of SCCs are explained in this chapter.

In Chapter 5, conclusions of the thesis and recommendations for future studies are given.

CHAPTER 2

LITERATURE REVIEW

2.1 General

The following literature review focuses on the definition and properties of self compacting concretes (SCCs). Brief information about the structure, formation and properties of mineral admixtures, namely, volcanic pumice and silica fume, are presented. Moreover, the effects of mineral admixtures on the fresh, hardened, and durability properties of SCCs are discussed.

2.2 Self Compacting Concrete

2.2.1 Development of self-compacting concrete

The problem of the durability of concrete structures was a chief matter of interest in Japan. The creation of durable structure of concrete requires adequate compaction by skilled workers. However, the gradual reduction in the number of skilled workers in Japan's construction industry has led to a similar reduction in the quality of construction work. One solution for the achievement of durable concrete structures independent of the quality of construction work is the employment of self-compacting concrete (Okamura and Ouchi, 2003).

It can be compacted into every corner of a formwork, only by means of its own weight and without mechanical vibration, the necessity of this type of concrete was proposed by Okamura in 1986.

Studies to develop self compact concrete, including a primary study on the workability of this concrete, have been carried out by Ozawa and Maekawa at the University of Tokyo (Ozawa, 1989; Okamura, 1993; Maekawa, 1999).

These models of self compact concrete were first concluded in 1988 by using materials by now on the market. This model of self compact concrete performed acceptably with regard to drying and hardening shrinkage, denseness after hardening, heat of hydration, and other properties. This type of concrete known "High Performance Concrete" and it was defined as follows at the three stages of concrete:

(1) Fresh: able to compact by its self,

(2) Early on age: prevention of early defects, and

(3) After the hardening: defense against exterior factors.

In the same point in time, "High Performance Concrete" is known as a concrete with high durability with a low water-cement ratio (w/c) by Professor Aitcin (Gagne et al., 1989). Seeing as, the name high performance concretes have been used in the worldwide to submit to high durability concrete. For this reason, the researchers have changed the name for the proposed concrete to "Self-Compacting High Performance Concrete".

Self Compacting Concrete (SCC) is known as concrete that have good deformability. Also have high resistance to segregation and also can filling closely reinforced areas and no need to vibration. To have excellent self-compact ability in heavily reinforced areas, self compact concrete should deform fit without any segregation of its component under its own weight. Providing that deformability under self-weight in the most common case in practical concrete placing, the slump flow test can be applied as an evaluation test for estimating deformability of SCC. However, there were still no standard tests for evaluating self-compact ability and resistance to segregation of SCC at that time. Then, the authors developed evaluation testing methods for simple application at industrialized stages and structure sites. The self-compact concrete capability testing method using a U-shaped apparatus and the time to (500 mm) flow testing method described (Shindoh, 1990).

High resistance to segregation and high deformability of self compact concrete were important properties. Since these properties are essentially opposite in nature, they are inclined to be sensitive to quality fluctuations of materials compared to predictable concrete when manufactured at ready-mixed concrete plants. It was still difficult to production of self compact concrete with a constant quality at an ordinary ready-mixed concrete plant at the time, because facilities and quality control of materials had not reached the required level. For improvement of manufacturing and handling, the authors developed a self compact concrete with a special kind of viscosity agent, which is derived from a biotechnology process. It is possible to increase resistance to segregation with commonly available materials and production facilities. At present, by JSCE recommendation (JSCE, 1999), this type of SCC is recommended as a Combination-type that is regular to provide the required self-compact ability primarily by reducing the water-powder ratio (in effect increasing the powder contents) to achieve adequate resistance to segregation and using superplasticizer to impart high deformability.

Since the world's first application using the Combination type SCC in 1991 for the main tower of a cable-stayed PC bridge and building structures including concrete-filled tubes, a total of 120,000 m^3 of field experience has been accumulated for the combination type SCC. It has been used for more complicated and important structures in recent years, such as an immersed tube-tunnel with a full sandwich structure, and large-section tunnels constructed with the Multi-Micro Shield tunnel Construction method (Tanaka, 2001).

As mentioned above, it has been more than ten years since the first practical use of SCC. Nowadays, structures built with SCC vary widely and each application requires different abilities. On the other hand, original methods of estimating self-compact ability, deformability and resistance to segregation and a process for deciding the optimum mix proportions of SCC with high self-compact ability are still used now. This proves that this tactic is sufficiently effective. Therefore, it is very significant to relate these evaluation methods and introduce basic concepts of development of SCC for improved manufacturing and handling (Shindoh and Matsuoka, 2003).

2.2.2 Mechanism for achieving self compacting ability

Okamura and Ozawa (1995) have engaged to achieving self compacting ability involves not only high workability of mortar or paste mortar only, but also to resistance the segregation among mortar and coarse aggregate when the self compact concrete flows through the limited area of high reinforcing bars. And the methods to achieved self compact ability were used superplasticizer, limited aggregate content, and finally used low water/powder ratio.

Previous studies have investigated that the increased internal stress caused the energy which is needed for flowing, thus resulted the obstruction of aggregate particles (Okamura and Ouchi, 2003).

The limitation of the particles in coarse aggregate, whose energy consumption is particularly intense, to lower level than normal is effective to avoid this kind of obstruction. And also highly viscous paste is lead to avoid the obstruction of coarse aggregates particles when the flowing of concrete through obstacles. When concrete is deformed, also the local increasing in internal stress caused by the approach of coarse aggregate particles was prevented when the high viscosity paste was used. By keeping the water-powder ratio at low level and by only the employment of a superplasticizer, high deformability can be achieved (Okamura and Ouchi, 2003).

Taisei Group was developed the U-flow test. The height that the concrete reaches after flowing through an obstruction From U-flow test can lead to the degree of comparability. The Concrete considered self compact concrete if the height of filling over 300 mm in this test. The L-Box tests are more suitable for detected if concrete have or no, higher possibility of segregation among mortar and coarse aggregate (Hayakawa et al., 1993).

If the mixture of concrete is judged to be having insufficient self compact ability during the U-flow and L-box test, this has to be detected quantitatively so that the mixture proportion can be adjusted. Slump-flow and V-funnel tests have been wished-for testing refuse ability and viscosity, respectively. The slump flow test and V-funnel test for paste and mortar have been planned to illustrate materials used with self compacted concrete, for example powder material, sand, and superplasticizer. Testing methods for the paste properties were also proposed and the indices for deformability and viscosity were also defined. The high value of Vm indicates higher deformability and the low value of Rm indicates higher viscosity. Characterizing methods for materials were proposed using the Vm and Rm indices (Okamura and Ouchi, 2003).

2.3 Mineral Admixtures Used in Concrete Production

2.3.1 Mineral admixtures

The most often used mineral admixture in the concrete industry is pozzolan. According to American Concrete Institute (ACI), a pozzolan is defined as “siliceous or siliceous and aluminous materials which in themselves possesses little or no cementitious value but will, in finely divided form and the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties”. ACI 231 defines a chemical reaction between the siliceous and/or siliceous-alumina components in the pozzolan, calcium hydroxide and water as pozzolanic reaction (Özbay, 2007).

There are two types of pozzolan, namely natural pozzolan and man-made pozzolan. Natural pozzolans are of volcanic origin (these were used by the early Romans and Greeks) such as trass, certain pumicites, perlite, and kaoline. Man-made pozzolans include industrial by-products such as silica fume, fly ash, and blast furnace slag (Güneyisi, 2004).

2.3.1.1 Volcanic pumice

A volcanic originate pumice is a new rock in world Industry and is becoming more and more popular and useful in time, and is used in Turkish industry for the last 20 years (Yildız and Uğur, 2009).

The Al_2O_3 in its structure gives its strength against fire and high temperature. There are two kinds of pumice in nature, Acidic and alkaline. Pumice has its usage in construction sector due to its high silica component. Turkey has high reserves of pumice. There has been an estimated 3 billion m^3 in explored fields (Gündüz et al., 1998). Pumice is a natural pozzolana with a volcanic origin. Besides its pozzolanic properties, it has not got sufficient usage in cement industry. Although there are several studies to use it as a light aggregate in concrete production, there are only a few to use it as a mineral admixture. After searching the literature, we have find out limited number of studies on pumice’s usage in cement as pozzolana. There is a suggestion of replacement of pumice powder for cement up to 15% to produce portland volcanic pumice cement (Hossain, 2003).

The most widely used cement in the world today as asserted by Shetty (2005) and Mehelcic (2003) is the ordinary Portland Cement (PC) manufacture from modern pre-calcining plants. The production of the PC rose from less than 2 million tons in 1880 (Mehelcic, 2003) and about 2.3 billion tons in 2005. Despite the dominance of the world cement market by PC; its production is characterized by intense energy demand and environmental pollutions. Also that for the production of 1 ton of cement, about 1 barrel of fuel or ¼ ton of coal is needed for the calcinations of the limestone. The European Commission (2001) affirmed that about 50% of the total cost of producing 1 ton of Portland cement is spent on energy alone. The second major challenge in the production of the cement is the emission of CO_2 into the atmosphere.

Day (1990), Horst (2001), Detwiler et al. (1996), and Naik (2005) asserted that for each ton of PC produced, about a ton of CO_2 and other pollutants are released into the atmosphere. There is a need therefore to reduce the cement content in concrete mixtures. According to Detwiler et al. (1996), this can be reduced by cement blending with supplementary cementitious materials (SCMs). Day (1990) recommended the use of pozzolanic materials of volcanogenic origin in the concrete mixes which can reduce energy consumption, limit CO_2 release into the atmosphere, and also increase concrete strengths and enhanced its durability.

The pumice deposits (natural pozzolans) are therefore potential cementitious materials for use in concrete mixes. The study accordingly aims at assessing the pozzolanic activity of pumice materials as potential natural pozzolans for sustainable cementitious materials in cement blending (Dadu et al., 2012).

American Society for Testing and Material (ASTM C618, 2005) defined the pozzolans as siliceous or siliceous and aluminous materials, which in themselves possess little or no cementitious values but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties. Kurtis (2002) and Day (1990) classified the pozzolans into natural and artificial; and stated that the artificial pozzolans are residues of waste industrial products such as silica fume and rice husk; while the natural pozzolans are products of volcanogenic activities such as volcanic ash, volcanic tuff, volcanic lava, pumice, shale's and diatomaceous. Also there are two classes of natural pozzolans; natural pozzolan requiring energy inputs prior to grinding (these include metakaolin and iatomaceous earths); and natural pozzolans requiring no energy inputs prior to utilization. Pumice rocks contents amorphous siliceous and aluminous materials; and are natural pozzolans requiring no energy inputs prior to grinding and can be used as in cement blinding to improve the compressive strength and enhancement of the durability of concrete.

Also pozzolanic materials are added to cement mix for following practical reasons (Brandt, 2009):

1- To increase concrete density, impermeability and strength,
2- To improve the workability without increasing cements content,
3- To decrease risk of segregation during transport and handling,
4- To decrease cement content for lower heat generation and cost, and
5- To improve resistance of concrete in environments with various chemicals.

2.3.1.2 Silica Fume

The American Concrete Institute (ACI) was defined the silica fume (SF) "Dead-smooth non-crystalline silica formed in electric arc furnaces as a by-product of the manufacture of the silicon's elemental or metals having silicon" (ACI 116R). It is usually a gray powders color, to some extent like to ordinary Portland cement and some fly ashes. Silica fume is usually classified as a supplementary cementitious material (FHWA, 2005).

That term refers to materials can used in concrete as additives to Portland cement. Because of silica fume's chemical and physical properties, the most important uses for silica fume were in concrete mixture, it is very reactive pozzolans material (Özbay, 2007).

Concrete made with silica fume can have durable with high value in compressive strength. Silica fume is available from suppliers of concrete admixtures and, when particular, it can add during concrete mixture. The concrete contractor needs special notice for Placing, finishing, and curing for silica-fume concrete require. Silicon metal and alloys are produced in electric furnaces. The raw materials are quartz, coal, and woodchips. The smoke that results from furnace operation is collected and sold as silica fume, rather than being land filled. Perhaps the most important use of this material is as a mineral admixture in concrete. Silica fume consists primarily of amorphous (non-crystalline) silicon dioxide (SiO_2). The individual particles are extremely small, approximately 1/100th the size of an average cement particle. Because of its fine particles, large surface area, and the high SiO_2 content, silica fume is a high reactive pozzolan when used in concrete. The quality of silica fume is specified by ASTM C 1240 and AASHTO M 307. High-strength concrete is a very economical material for carrying vertical loads in high-rise structures. Until a few years ago, 6,000 psi concrete was considered to be high strength. Today, using silica fume, concrete with compressive strength in excess of 15,000 psi can be readily produced. Concrete made with silica-fume and low water content is greatly resistant to penetration by chloride ions. The increasingly transportation agencies will use silica fume in concrete for construction of new bridges or treatment of existing structures. A specifies must make a conscious decision to include it in concrete to achieve desired concrete properties. Silica fume for use in concrete is available in wet or dry forms. It is usually added during concrete production at a concrete plant. Concrete with silica fume can be created successfully in dry-batch plants and centralmix. Assistance is readily available on all aspects of handling silica fume and using it to produce consistent, high-quality concrete Silica-fume concrete should be transported, placed, finished, and cured following the good concreting practices outlined by the American Concrete Institute. Flatwork containing silica fume concrete generally requires less finishing effort than conventional concrete. To gain the most benefits from using silica fume, the concrete must be cured effectively (http://www.silicafume.org/general-silicafume.html).

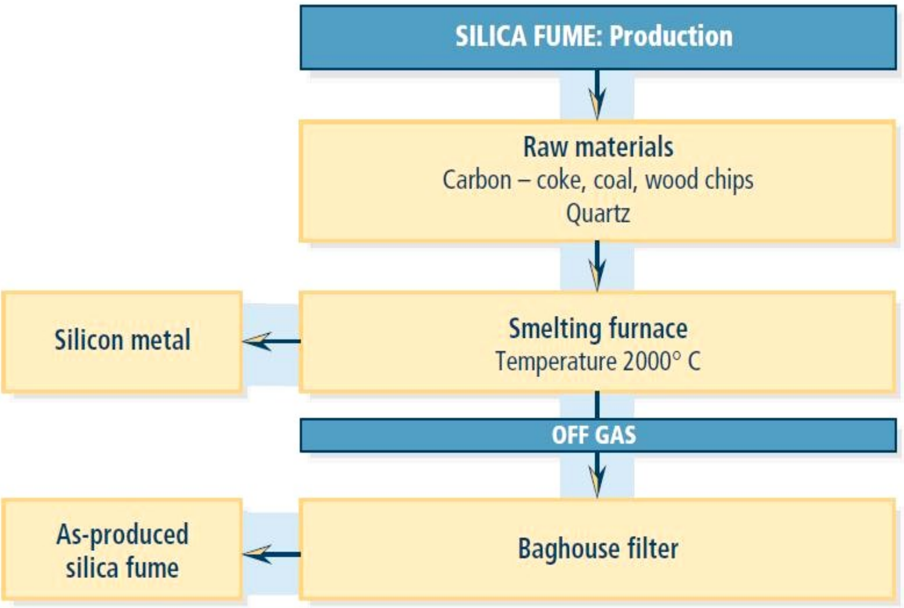


Figure 2.1 Plane of silica fume production (FHWA, 2005)

Silica fume, also referred to as microsilica or condensed silica fume, is a byproduct material that is used as a pozzolans (Figure 2.2). This byproduct is a result of the drop of high-purity quartz with coal in an electric arc furnace in the manufacture of silicon or ferrosilicon alloy. Silica fume raises as an oxidized vapor from about 2000°C furnaces. When it cools it condenses and is collected in huge cloth bags. The condensed silica fume is then processed to remove impurities and to control particle size. Condensed silica fume is essentially silicon dioxide (usually more than 85%) in non crystalline (amorphorous) form. Since it is an airborne material like fly ash, it has a spherical shape (Figure 2.3). It is extremely fine with particles less than 1 μm in diameter and with an average diameter of about 0.1 μm, about 100 times smaller than average cement particles. Condensed silica fume has a surface area of about (20,000 m^2/kg) (nitrogen adsorption method). For comparison, tobacco smoke's surface area is about 10,000 m^2/ kg. Type I and Type III cements have surface areas of about 300 to 400 m^2/kg and (500 to 600) m^2/kg (Blaine), respectively. The relative density of silica fume is generally in the range of 2.2 to 2.5. Portland cement has a relative density of about 3.15. The bulk density (uncompacted unit weight) of silica fume varies from (130 to 430 kg/m^3). Silica fume is sold in powder form but is more commonly available in a liquid. Silica fume is used in amounts between 5% and 10% by mass of the total cementations material. It is used in applications where a high degree of impermeability is needed and in high strength concrete. Silica fume must meet ASTM C 1240 (Kosmatka, 2002).

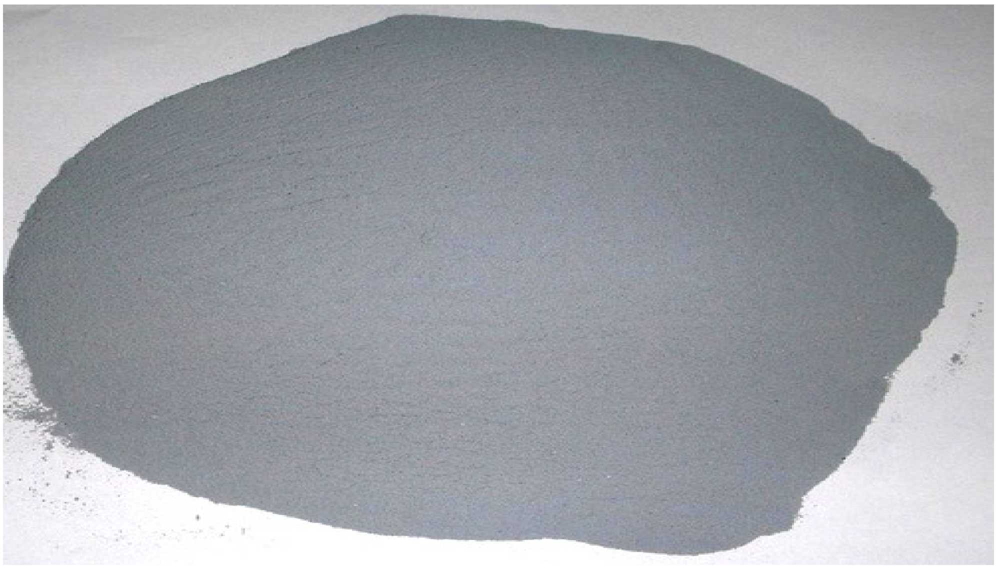


Figure 2.2 Silica fume powder (http://www.vitechvn.com.vn)

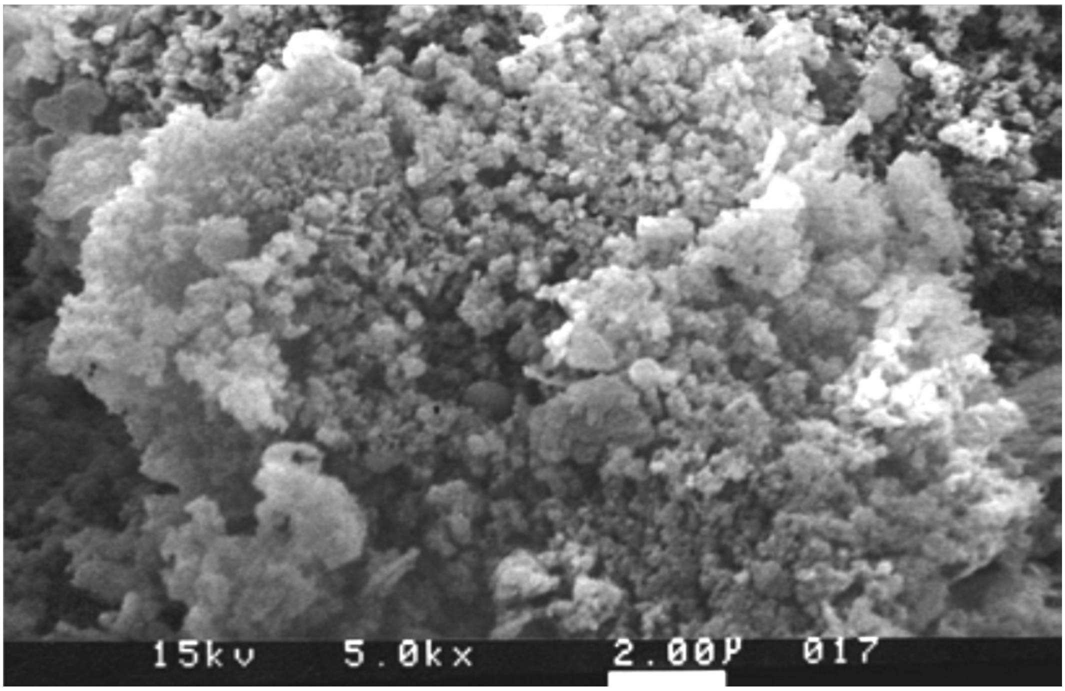


Figure 2.3 Scanning electron microscope micrograph of silica fume particles at 20000x (Kosmatka, 2002)

- Physical contributions - adding silica fume brings millions and millions of very small parades to a concrete mixture. Just like fine aggregate fills in the spaces between coarse aggregate particles, silica fume fills in the spaces between cement grains. This observable fact is frequently referred to as parade packing or micro-filling. Even if silica fume did not react chemically, the micro-filler effect would bring about significant improvements in the nature of the concrete (FHWA, 2005).
- Chemical contributions -Because of its very high amorphous silicon dioxide content, silica fume is a very reactive pozzolanic material in concrete. As the Portland cement in concrete begins to react chemically, it releases calcium hydroxide. The silica fume reacts with this calcium hydroxide to form additional binder material called calcium silicate hydrate, which is very similar to the calcium silicate hydrate formed from the Portland cement. It is

largely this additional binder that gives silica-fume concrete its improved hardened properties (FHWA, 2005).

2.3.2 Effects of mineral admixtures on the fresh properties of concretes

2.3.2.1 Effects of volcanic pumice on the fresh properties of concretes

The slump values of volcanic pumice concrete (VPC) mixtures increased with the increase of VP up to approximately 20% and then decreased with the increase of VP. The slump values of VPC mixtures having up to 40% of VP were found to be greater than the control mixtures with 0% VP. This implied that the addition of VP up to 40% was beneficial in improving the workability of VPC mixtures (Hossain and Lachemi, 2004).

Generally, air content of the VPCs increased with the increase of VP content. This can be attributed to the replacement of finer normal Portland cement by comparatively coarser VP. The air content, however, is also dependent on the other mixture parameters. Air content may lead to the increase in workability and decrease in strength and density of concrete (Hossain and Lachemi, 2006).

Also the decrease in normal consistency is due to the reduction of cementitious binder in the fresh mixture with the increase of VP content. On the other hand, specific gravity of VP is less than that of cement, which resulted in the larger volume VP compared to the volume of cement replaced as the replacement was made by mass. As a result, the overall volume was increased needing more water to form a paste of same consistency for different replacement of VP in the mixture. Finally this is reasonable as the increase of VP content reduces the cement content in the mixture and also decreases the surface area of the cement. As a result, the hydration process slows down causing setting time to increase. The slow hydration means low rate of heat development (Hossain, 2003).

2.3.2.2 Effects of silica fume on the fresh properties of concretes

The water demand of concrete increases with increasing the amounts of silica fume used due primarily to its high surface area (Scali et al., 1987; Caretta and Malhotra, 1983). Fresh concrete containing silica fume is more cohesive and less prone to segregation than concrete without silica fume. As the silica-fume content increases, the concrete may appear to become sticky. 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. Additionally, the silica fume reduces bleeding by physically blocking the pores in the fresh concrete (ACI 234 R-96, 1996). Silica-fume concrete usually includes chemical admixtures that may affect the time of setting of the concrete. Previous experiences indicate that the setting time is not significantly affected by the use of silica fume alone. Practical control of the setting time may be achieved by using appropriate chemical admixtures. In the literature, there is a general agreement on the retardation of initial and final setting times of the concretes containing FA and GGBFS. The behavior seen in the SF concretes was different from those with FA and GGBFS in that the addition of SF generally reduced the initial and final setting times of the concretes, especially at 10 and 15% replacement levels. No general agreement could be found in the literature considering the effect of SF content on the setting times of concretes (Gesoğlu and Özbay, 2007). Some researchers (Brooks et al., 2000; Alshamsi et al., 1993; Khedr and Abou-Zeid, 1994) stated that SF has retarding effect while some others reported its accelerating effect on the setting times. According to Pistilli et al. (1984) and De Almeida and Goncalves (1990), for a lower water/binder ratio concrete containing a superplasticizer, the effect of SF was to reduce the setting times when compared to those of control concrete containing the same amount of superplasticizer.

2.3.3 Effects of mineral admixtures on the hardened properties of concretes

2.3.3.1 Effects of volcanic pumice on the hardened properties of concretes

The compressive strength is found to decrease with an increase of VP content (Hossain, 1999). This is reasonable due to the reduction of cement content in the mix with the increase of VP content. The finely divided silica (61%) in VP can combine with calcium hydroxide (liberated by the hydrating PC) in the presence of water to form stable compounds such as calcium silicates, which have cementitious properties. Such pozzolanic action of VP contributes to the enhancement of strength and long-term durability (Hossain, 1999).

2.3.3.2 Effects of silica fume on the hardened properties of concretes

Since silica fume improves the bond between the paste and aggregate, the influence of the quality of the aggregate on the mechanical properties of concrete becomes more important in silica-fume concrete (Özbay, 2007).

Bhanja and Sengupta (2005) carried out an extensive experimental study over the water–binder ratios ranging from 0.26 to 0.42 and silica fume–binder ratios from 0.0 to 0.3. They were determined, compressive, flexural and split-tensile strengths at 28 days. The compressive, as well as the tensile strengths increased with silica fume incorporation, and the results indicated that the optimum content is not constant but depends on the water–cementitious material (w/cm) ratio of the mixture. When compared to splitting tensile strength, flexural strength has exhibited greater improvements.

According to ACI committee report (ACI 234 R-96, 1996) the static elastic modulus of silica fume concretes is apparently similar to that of Portland cement concrete of similar strength. Helland et al (1983) concluded that the stress-strain behavior of silica-fume concrete was similar to that of Portland-cement concrete. Sellevold and Nilsen (1987) found that the dynamic modulus of elasticity increases with increasing silica-fume content in pastes.

Mazloom et al. (2004) demonstrated that the compressive strength development of the concrete mixtures containing silica fume was negligible after the age of 90 days; however, there were 26% and 14% strength increase in the control concrete after one year compared to its 28 and 90 days strengths, respectively. At the age of 28 days, the strength of concrete containing 15% silica fume was about 21% higher than that of the control concrete. Therefore, the inclusion of silica fume in concrete mixture, mainly affects short-term strength of concrete. The difference in strength development in ordinary Portland cement concrete and silica fume concrete can be attributed (Wild et al., 1995) to the rapid formation of an inhibiting layer of the reaction products preventing further reaction of SF with calcium hydroxide beyond

90 days. In the case of the control concrete, hydration is at a less advanced stage and strength still shows significant improvement.

2.3.4 Effects of mineral admixtures on the durability properties of concretes

2.3.4.1 Effects of volcanic pumice on the durability properties of concretes

The variation of drying shrinkage (DS) in VPCs with different percentages of VP was slightly higher compared to control concrete (0% VP) especially within the first 6 weeks. The 12-week DS in 10, 20, 30, and 40% were approximately 538, 540, 528, and 516 microstrain, respectively, compared to approximately 493 microstrain in control concrete. The increase in VA content beyond 20% seemed to reduce the DS. The DS of 10 and 20% VACs were higher than those of 30 and 40% VACs although the overall shrinkage in VACs was higher than control concrete (0% VA) within the curing age of 12 weeks. The maximum DS did not exceed 600 microstrain for any VACs. A similar trend was observed by Gopalan and Haque (1987) in FA concrete. However, Samarin and Ryan (1975) reported that good-quality Australian fly ashes usually result in a reduction of shrinkage compared to control normal Portland cement concrete. The DS is affected by twin influences of total aggregate to binder ratio and w/b. DS increases with the increase of w/b and decreases with the increase of total aggregate to binder ratio for normal concrete. For the VPCs in mixture with (w/b of 0.45), the total aggregate to binder ratio decreased from 4.5 to 4.4 while VP content increased from 0 to 40%. This may be one of the contributing factors, among others, for higher DS in VPCs compared to control concrete.

The pozzolanic reaction between VP and calcium hydroxide takes place at a slower rate and produces a denser concrete as the age of concrete increases. The denser VPCs with the increase in age should exhibit lower permeability as is confirmed from the 91-day permeability. The reduction of permeability with age may have beneficial effect of improving the long-term corrosion resistance of VPCs, and for resistance of VPCs against chloride-ion penetration, when comparison among different concretes the results showed better chloride resistance and lower permeability of VPCs as compared to normal Portland cement concrete. The increase of VP from 0 to 40% resulted in a more than 40% increase in chloride-ion resistance. Chloride-ion resistance of VPCs increased with an increase of VP content. ASTM C 1202-97 specifies the concrete as highly permeable if the charge that passes through it is more than 4000 Coulombs. All VPCs showed values lower than 4000 Coulombs (Hossain and Lachemi, 2006).

2.3.4.2 Effects of silica fume on the durability properties of concretes

Alexander and Magee (1999) examined the durability performance of various condensed silica fume (SF) concretes in comparison to Portland cement (PC) and PC/GGBFS controls. Oxygen permeability index, water sorptivity, chloride conductivity tests were performed on the produced concrete samples and the test results indicated that durability performance was significantly improved when using SF in all tests. Pigean et al. (1986) investigated the freeze-thaw durability of concrete with and without silica fume in accordance with the requirements of ASTM Test Method for Resistance of Concrete to Rapid Freezing and Thawing (C 666 Procedure A). The water-cement ratio of all mixes was 0.5, and the silica-cement ratio of the silica fume mixes being 0.1. The test results showed that the critical value of the air-void spacing factor in these ASTM C 666 tests is significantly lower for the silica fume concretes. Such concretes therefore appeared to be more susceptible to internal cracking caused by rapid freeze-thaw cycles in water, even though the use of silica fume decreased the surface scaling of the test specimens. This confirms that scaling and internal cracking are two different forms of frost damage caused by rapid freeze-thaw cycles in water.

2.4 Blended Cement

American Society for Testing and Material (ASTM C 150, 2005) defined blended cements (BC) as cement mixtures containing ordinary Portland cement (PC) and one or more supplementary cementing materials (SCMs); with the potential benefits of reducing the overall concrete costs, improving concrete workability, durability and long term strengths. Horst (2001) elucidated Further that BC as a technical term often refers to cement products that are factory blended by cement companies while on the site mixing with the PC is referred to as 'partial replacements'. As stated earlier in this report, pozzolans are utilized as SCMs in cement blending or partial replacements of the PC in concrete mixes.

2.5 Sustainability and Environmental Benefits

The concentration of CO_2 emissions in the atmosphere, resulting from PC manufacturing varied from 5% to 10% of the green house gases. The World Business Council for Sustainable Development (WBCSD) thus in 2002 recommended the reduction of CO_2 emissions from cement manufacture processes by 30% by 2020; and 60% by 2050. These levels of CO_2 emissions obviously make the cement manufacturing unsustainable. Horst (2001), and Azmar (2003) tested that these emissions problems are real; as every ton of Portland cement produced, the CO_2 released to the atmosphere by the burning fuel is between 1 to 1.25 tons. Econoler International (2009) reported that the cement industry accounts for about 5% of the annual global anthropogenic carbon dioxide emissions; representing about 1,800 million tons of CO_2 emissions in 2005 from the use of fossil fuels. Thus, a reduction in PC production directly reduces the emissions of CO_2 to the atmosphere from the cement manufacturing. Consequently, a reduction of the PC in concrete mixes will create a substantial reduction of the green house gases (GHG) emissions.

The sustainability theory for the use of SCMs such as the pumice is that even if, it is a small reduction of the PC in concrete uses per ton of concrete produced; the resultant environmental benefits are large because of the enormous quantity of concrete consumed daily worldwide. Thus, a replacement of any quantity of the PC directly reduces the emissions of CO_2 to the atmosphere. The use of SCMs will consequently lessen the burden of the green gasses release cement calcinations (Dadu et al., 2012).

Volcanic activities are common in various parts of the world and due to frequent volcanic eruption, volcanic debris such as: volcanic ash and pumice are found abundantly. The 1994 volcanic eruption that occurred in the East New Britain province of Papua New Guinea was the second most destructive one in history, which completely devastated the province and created an environmental disaster. A comprehensive research program was carried out with motivation from local cement and construction industries, in an attempt to explore the possible utilization of volcanic debris in cement and concrete production. This could not only provide low cost concrete but also help to decrease environmental hazards (Hossain, 2005).

The research provided useful information on the properties of volcanic ash (VA) and volcanic pumice (VP) based cement, mortar and concrete. Research suggested the manufacture of blended PVAC (Portland volcanic ash cement) and PVPC (Portland volcanic pumice cement) similar to PFAC (Portland fly ash cement) with maximum replacement of up to 20% (Hossain, 2003).

The meaningful use of volcanic debris such as VA can not only transform it into a natural resource to produce low-cost construction materials but also can help to decrease environmental hazards (created due to the deposition of volcanic materials on the land), leading to sustainable development. The development of less expensive and environmentally friendly (the use of VA as a cement replacement can lower greenhouse gas emissions associated with the production of cement as well as provide a safe way for the removal of such debris) VA-based concrete with acceptable strength and durability characteristics can be extremely helpful in the development and rehabilitation of volcanic disaster areas around the world (Hossain and Lachemi, 2006).

CHAPTER 3

EXPERIMENTAL PROGRAM AND METHODOLGY

3.1. Introduction

The properties of SCCs made with volcanic pumice powder and silica fume was investigated through an experimental program which involves mainly two parts. Firstly, SCC was produced volcanic pumice with cement. And, in second stage the production of SCCs with volcanic pumice powder and silica fume with cement. The slump flow, flow time, V-funnel flow time, and L-box height ratio tests were considered to identify required properties and characteristics of fresh SCCs. The hardened concretes were tested for the compressive strength at 3, 7, 28, and 90 days for the evaluation of mechanical properties. Moreover, the durability tests were conducted to investigate the resistance to chloride ion penetration, water absorption sorptivity index, and gas permeability at the ages of 28 and 90 days.

3.2. Materials

3.2.1. Cement

Portland cement was used in our study (Portland cement CEM I 42.5R) conforming to the TS EN 197-1, which mainly based on the European EN 197-1. It had a specific gravity of 3.15 and Blaine fineness of 326 m^2/ kg and its chemical and physical properties is given in Table 3.1.

Table 3.1 Chemical compositions and physical properties of cement and mineral admixtures

Analysis report (%)	Portland cement	SF	VP
CaO	63.60	0.45	14.1
SiO2	20.25	90.36	49.5
Al2O3	5.31	0.71	16.4
Fe2O3	4.04	1.31	14.7
MgO	2.82	----	1.9
SO3	2.73	0.41	0.2
K2O	0.92	1.52	1.3
Na2O	0.22	0.45	0.1
Loss on ignition	3.02	3.11	1.3
Specific gravity(kg/cm^3)	3.15	2.2	2.84
Specific surface area (m^2/kg)	326	21080	454.8

3.2.2. Silica fume

A commercial grade silica fume (SF) obtained from Norway was utilized in this study. It had a specific gravity of 2.2 kg/m^3 and the specific surface area (Nitrogen BET Surface Area) of 21080 m^2/kg. In Table 3.1, both the chemical analysis and physical properties of SF is provided.

3.2.3. Volcanic pumice powder

The granulated volcanic pumice obtained from volcanic mountains located in south of Turkey (Hatay city, Hassa county) were ground through ring mill in the laboratory to obtain pumice powder with blain fineness of 454.8 m^2/kg. Data showing the physical and chemical analysis of volcanic pumice powder (VP) are given in Table 3.1, and Figure 3.1 shows the view of volcanic pumice powder.

Figure 3.1 Volcanic pumice powder (VP)

3.2.4. Superplasticizer

A polycarboxylic-ether type superplasticizer (SP) with a specific gravity of 1.07 and pH of 5.7 was used in all mixtures. The properties of superplasticizer are given in Table 3.2 as reported by the local supplier.

Table 3.2 The properties of superplasticizer

Properties	Superplasticizer
Name	Glenium51
Color tone	Dark brown
Stat	Liquid
Specific gravity (kg/cm^3)	1.07
Description	Modified polycarboxylic type of polymer
Recommended dosage	% (1-2) binder content

3.2.5. Aggregate

The coarse aggregate used was river gravel with a nominal maximum size of 16 mm. As fine aggregate, a mixture of natural river sand and crushed limestone was used with a maximum size of 5 mm. The coarse aggregate had a specific gravity of 2.72 and its water absorption was 0.45%. The specific gravity and water absorptions of natural river sand and crushed limestone were 2.66 and 2.45 g/cm^3, and 0.55% and 0.92%, respectively. The particle size gradation obtained through the sieve analysis and physical properties of the fine and coarse aggregates are presented in Table 3.3. Grading curves of fine and coarse aggregates associated with that of the control mixture are presented in Figure 3.2.

Table 3.3 Sieve analysis and physical properties of the fine and coarse aggregates

Sieve size (mm)	**Fine aggregate**		**Coarse aggregate**
	River sand	**Crushed sand**	
16	100	100	100
8	100	100	31.5
4	86.6	95.4	1
2	56.7	63.3	0.5
1	37.7	39.1	0.5
05	25.7	28.4	0.5
0.25	6.7	16.4	0.4
Fineness modules	2.87	2.57	5.66
Specific gravity (gr/cm^3)	2.66	2.45	2.72
Water absorption (%)	0.55	0.92	0.45

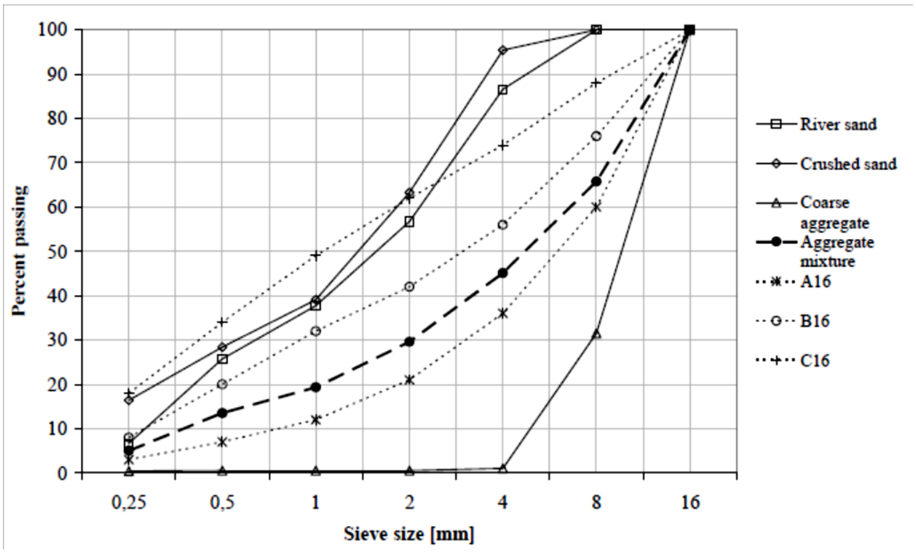


Figure 3.2 Grading of aggregates

3.3 Concrete Mixture Details

In this study, eight self compacting concrete mixtures was designed to cover a range of different mixture variations with constant water binder ratio of 0.37 and with total binder content of 520kg/m^3. In first group (M1-M4), the production of these group used (PC + VP), and the other (M5-M8) used (PC + SF + VP).

The replacement ratio for the VP was 0, 5, 10 and, 20% by weight of the total binder. In the design of the concretes within the second group used constant percentage of SF about 8% with the same replacement level of VP. Table 3.4 represents the mixtures proportions of SCCs.

Table 3.4 Concrete mixture proportions (kg/m^3)

NO.	**MIX ID**	**PC**	**SF**	**VP**	**Fine aggregate**		**Coarse aggregate**	**Water**	**SP**
					River sand	**Crushed sand**			
1	M1	520	0	0	529.7	198.2	930.9	192.4	10.4
2	M2	494	0	26	529.0	198.0	929.8	192.4	10.4
3	M3	468	0	52	528.4	197.7	928.7	192.4	10.4
4	M4	416	0	104	527.1	197.2	926.5	192.4	10.4
5	M5	478.4	41.6	0	524.9	196.4	922.5	192.4	10.4
6	M6	452.4	41.6	26	524.2	196.2	921.3	192.4	10.4
7	M7	462.4	41.6	52	523.6	195.9	920.2	192.4	10.4
8	M8	374.4	41.6	104	522.3	195.4	918.0	192.4	10.4

3.4. Concrete Casting, Test Specimens, and Curing

In the production of SCCs, the mixing sequence and duration are so important; it was employed to supply the same homogeneity and uniformity in all mixtures. The batching sequence consisted of homogenizing the fine and coarse aggregates for 30 sec in a rotary planetary mixer with capacity about 25 litters, after that added about half of the water mixing into the mixer and continuing to mix for one more minute. After that the cement and mineral admixtures were added, the mixing was resumed for another minute as show in Figure 3.3. Finally, the SP with remaining water was introduced, and the concrete was mixed for two minute and then left for one minute to rest. Eventually, the concrete was mixed for additional one minute to complete the mixing sequence. The concretes were designed to give a slump flow of 70±3 cm.

Fresh concrete tests will be starting to determine slump flow diameter, V-funnel flow time, and L-Box height ratio. The compressive strength, rapid chloride permeability, water absorption, sorptivity and gas permeability of SCCs were also determined in the hardened state. All of the specimens were cast full without any compaction and vibration. Specimens cast from a typical mixture consisted mainly of the following:

- Twelve 150 mm cubes for the compressive strength evaluation at 3, 7, 28 and 90 days,

- Eight 100x200 mm cylinders for rapid chloride permeability and sorptivity evaluation at 28 and 90 days, and

- Two 150x300 mm cylinders for gas permeability evaluation at 28 and 90 days.

After 24 hours of casting the samples were demoulded and cured in water until the testing ages.

Figure 3.3 Concrete mixing

3.5 Tests for Fresh Properties

The slump flow, $T_{500\text{ mm}}$ flow time, V-funnel flow time and L-box height ratio tests were carried out to identify the required properties and the characteristics of fresh SCCs mixtures with the recommendations given in EFNARC (EFNARC 2005).

3.5.1 Slump Flow Test

To measure the slump flow, an ordinary slump flow cone is filled with SCC without any compaction and leveled. The cone is lifted and average diameter of the resulting concrete spread is measured as seen Figure 3.4. In this study, slump flow diameter of all the mixtures was increased. In the slump flow test, the time ($T_{500\ mm}$) was also measured which determines the time taken for the concrete to reach the 500 mm spread circle. A lower time indicates greater flowability.

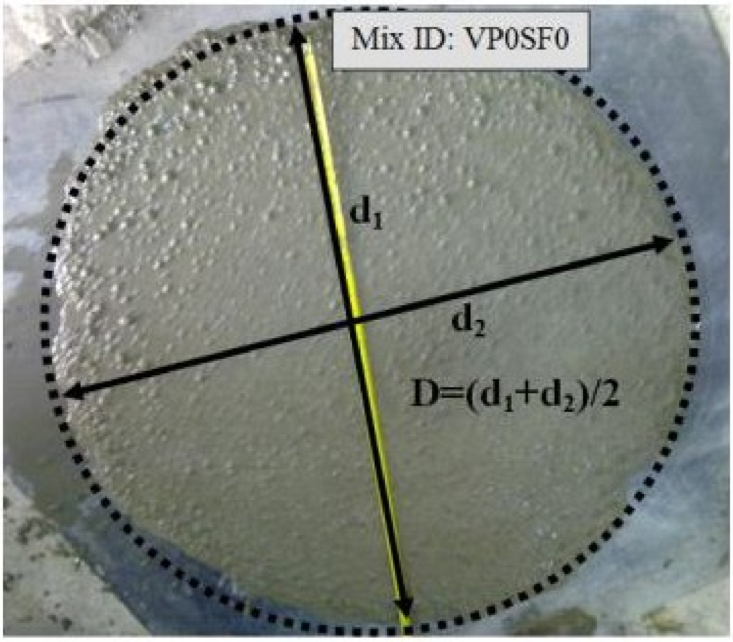


Figure 3.4 Slump flow test

3.5.2 V-Funnel Flow Test

In evaluating the filling ability and the viscosity of the concrete mixtures the V-Funnel test was conducted as presented. The fill time is determined using a simple procedure in which the funnel is completely filled with fresh concrete, measured the flow time between the opening of the orifice and the complete emptying of the funnel. Best fill able and Table concrete would take short time to flow out. The test is shown in Figure 3.5.

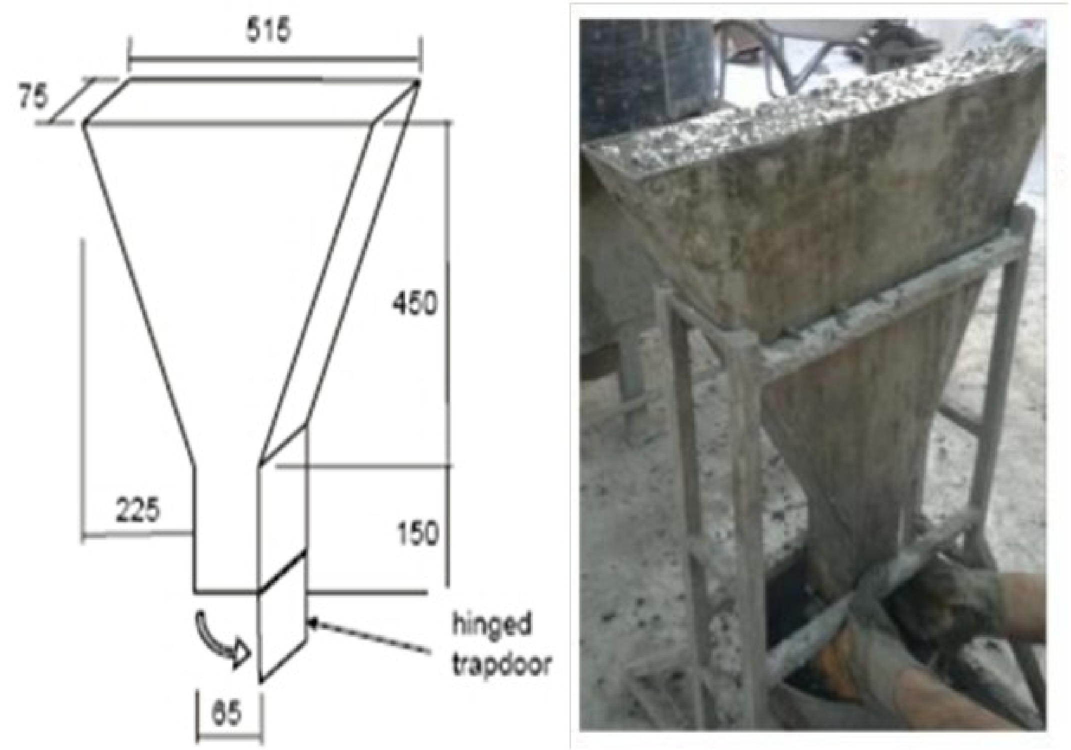


Figure 3.5 V-funnel test

3.5.3 L-box test

The L-box apparatus consists of a rectangular-section box in the shape of an ‘L’, with a vertical and horizontal section, parted by a moveable gate, in front of which vertical portions of a reinforcement bar are provided in Figure 3.6. The vertical section is filled with concrete, and then the gate is lifted to allow the concrete flow into the horizontal section. When the flow has stopped, the highness of the concrete at the end of the horizontal section is declared as a ratio of that residual in the vertical section. This is a signal of passing ability, or the degree to which the passage of concrete between the bars is limited. L-box test reviews filling and passing ability of SCCs and serious lack of stability (segregation) can be discovered visually. Segregation may also be discovered by following sawing and checking sections of the concrete in the horizontal section. Typical approval values according to EFNARC are in the range of 0.8 to 1.0. If the concrete flows as freely as water, at rest it will be horizontal, so H2/H1 reaches 1.

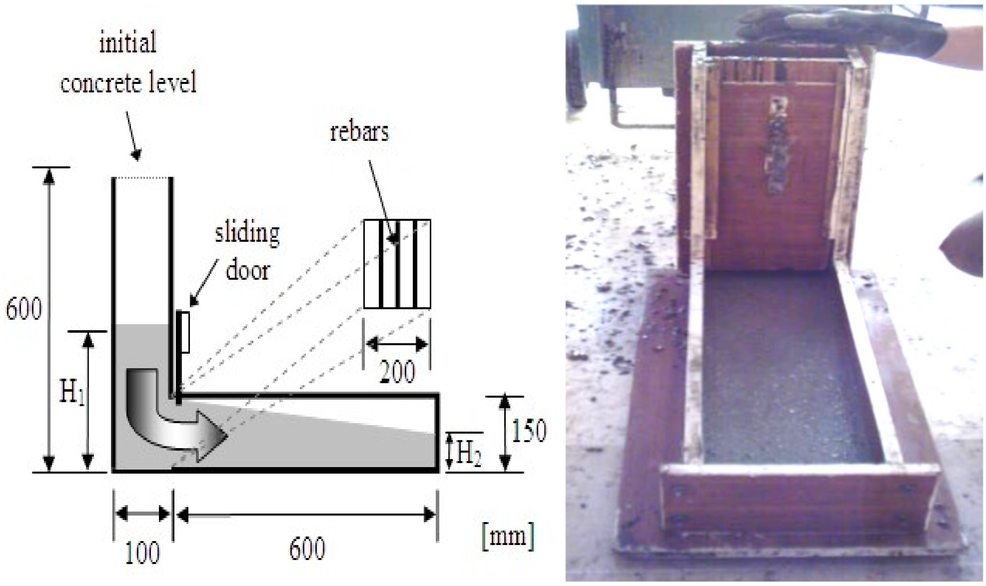


Figure 3.6 L-box test

3.6 Tests for Harden Properties

3.6.1 Compressive strength

For compressive strength measurement of SCCs, 150*150*150 mm cubes were tested with respect to ASTM (ASTM C39, 2010) by means of a 3000 kN capacity testing machine. The test was conducted on three 150*150*150 mm cubes for each mixture at the ages of 3, 7, 28 and 90 days. Figure 3.7 shows the compression test.

Figure 3.7 Photographic view of compression test

3.6.2 Rapid chloride permeability

In order to conclude the penetration resistance of the concrete to chloride ions, rapid chloride permeability test (RCPT) was performed according to ASTM C1202. RCPT is based on the electrical conductivity of the concrete. Concrete discs of 100 mm in diameter and 50 mm in height were used for the test. The curved surface of the specimen is coated with paraffin first. Before the test as shown in Figure 3.8, a standard vacuum saturation procedure was applied to the specimens. Specimens were put between test cells, one of which containing NaCl solution and the other NaOH solution as seen in Figure 3.8. Then, the concrete sample was subjected to a potential difference of 60 Volts and the total charge was measured by data logger registered the current passing through concrete over six hours period and expressed in terms of Coulombs as a basis for the evaluation of the concrete chloride permeability. Terminating the test after 6 hours, ASTM C1202 had a classification to chloride permeability in concrete which consist of five classes starting from ‘High’ to ‘Negligible’ on the basis of the coulomb as shown in Table 3.5.

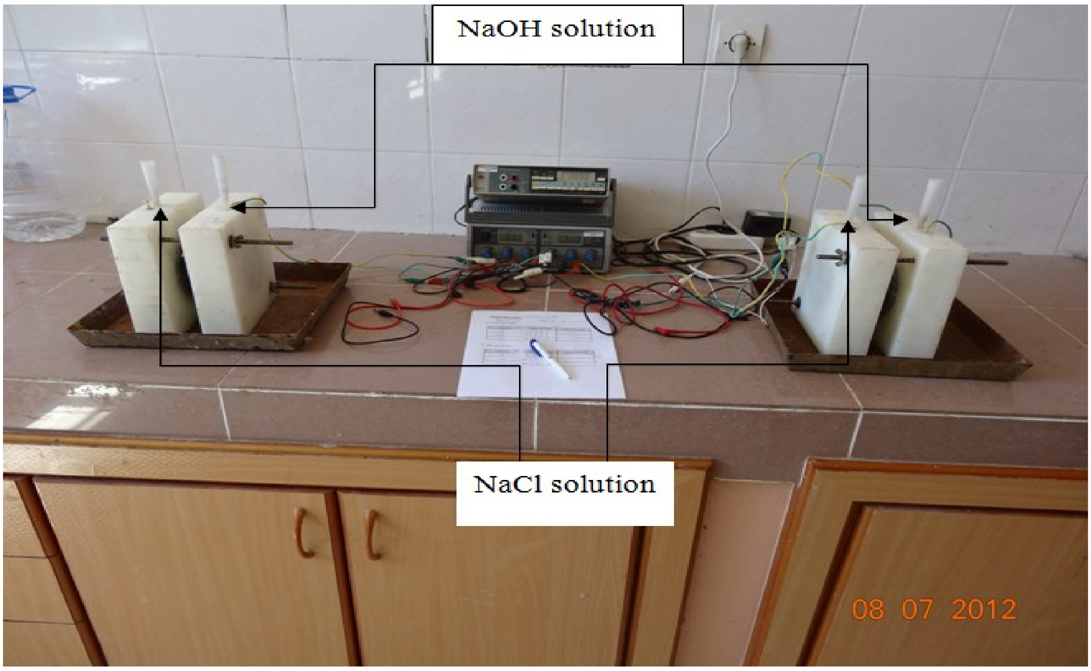


Figure 3.8 Photographic view of RCPT test

Table 3.5 Analysis of test results obtained using RCPT (ASTM C1202, 1993)

Charge passed (coulombs)	Chloride permeability	Typical of
>4000	High	High w/c ratio (>0.6) conventional PC
2000 - 4000	Moderate	Moderate w/c ratio(0.4-0.5) conventional PC
1000 – 2000	low	low w/c ratio(< 0.4) conventional PC
100 - 1000	Very low	Latex – modified concrete internally sealed concrete
>100	Negligible	Polymer – impregnated concrete polymer concrete

3.6.3 Gas permeability

The gas permeability of the concrete mixtures was performed by using a CEMBUREAU Method recommended by RILEM (RILEM TC 116-PCD, 1999). The graphic view and line diagram of the apparatus as well as the detail of the testing cell are shown in Figures 3.9 and 3.10. Three specimens were taken simultaneously for each concrete mixture after curing period of 28 and 90 days was ended. Each specimen should have a diameter of 150 mm and a thickness of 50 mm; concrete disc specimens cut from the mid portion of Ø150x300 mm cylinder. Cutting process must be careful to ensure the avoidance of cracking or any other damage. Oxygen gas was used as passing through medium, oxygen gas was applied to the specimens at difference pressures changeable from (150 to 500) KPa in pressure cells, which were protected by a strongly fitting rubber pressuring under high pressure next to the curved surface. Before testing the pre-conditioning of the specimens is necessary to obtain significant results.

For this the specimens would be dried at 100^{o} C in oven to guarantee maximum 1% weight change within the specimens. After oven drying process specimens were kept in a sealed envelope till test began. The average of three specimens was reported as a test result.

Underlying principle was Hagen- Poiseuille relationship (Picandet et al., 2001) for laminar flow of a compressible fluid through a porous body with small capillaries under steady-state conditions. The relationship solved for the specific permeability coefficient (Ka) can be written as follows:

$$\boldsymbol{Ka = \frac{2P_2QL\mu}{A(P_1^2-P_2^2)}} \qquad \textbf{(3.1)}$$

Where (Ka) is the gas permeability coefficient in m^2, P1 is the inlet gas pressure in N/m^2, P2 is the outlet gas pressure in N/m^2, A is the cross-sectional area of the sample m^2, L is the height of sample in m, μ is the viscosity of oxygen ($2.02x10^{-5.12}$ Ns/m^2), and Q is the volume flow rate in m^3/s.

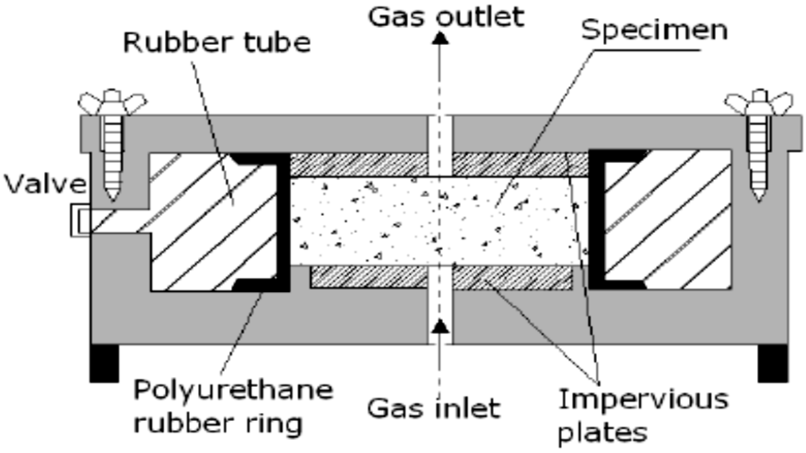


Figure 3.9 Schematic presentation of the pressure cell and test specimen

Figure 3.10 Photographic view of gas permeability test

3.6.4 Water absorption

Water absorption was determined using the up and bottom of sections of 100x200 mm cylinder specimens cast for RCPT. Thus, three disc samples cut from two Ø100x200 mm cylinders were tested for each concrete mixture at the age of 28 and 90 days. As per ASTM C 642, the specimens were initially weighted after pulled out of water and dried the surface (W1) then putted the samples in oven dried at 100 ^{0}C for 24 hrs to reach constant mass to obtain the oven-dry weights (W2). Eventually, the water absorption (WA) of each concrete was calculated through equation:

$$\boldsymbol{WA\%} = \frac{(\boldsymbol{W_1}-\boldsymbol{W_2})}{\boldsymbol{W_2}} * \mathbf{100\%} \qquad \textbf{(3.2)}$$

3.6.5 Sorptivity

The sorptivity test measures the rate of water intake the pores of concrete. Three test specimens having a diameter of Ø100 mm cut from Ø100x200 mm cylinders were employed. The specimens were putted in oven with 100^o C until constant mass and then allowed to cool to the laboratory temperature in a sealed container. Afterwards, the sides of the specimens were coated by paraffin, about 2-5 mm from bottom.

The sorptivity test was carried out by placing the specimens in basin glass water on rods. This procedure was considered to allow free water movement through the bottom surface only.

The specimens were removed from the basin glass and weighed at different time intervals started from 1-64 minute. The volume of water absorbed was calculated by dividing the mass gained by the nominal surface area of the specimen and by the density of water. Tests are shown in Figures 3.11 - 3.13.

By dividing the mass gained by the supposed surface area of the specimen the volume of water absorbed was calculated and the density of water then plotted with respect to square root of time. Sorptivity coefficient was represented as the slope of most excellent fit line.

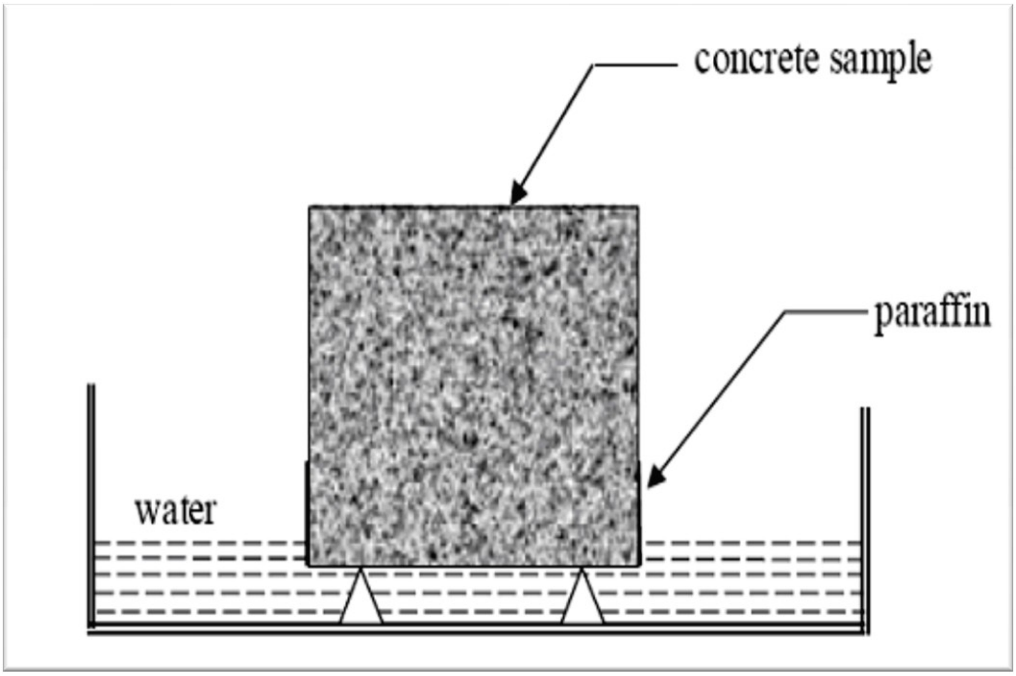


Figure 3.11 Schematic view of sorptivity test

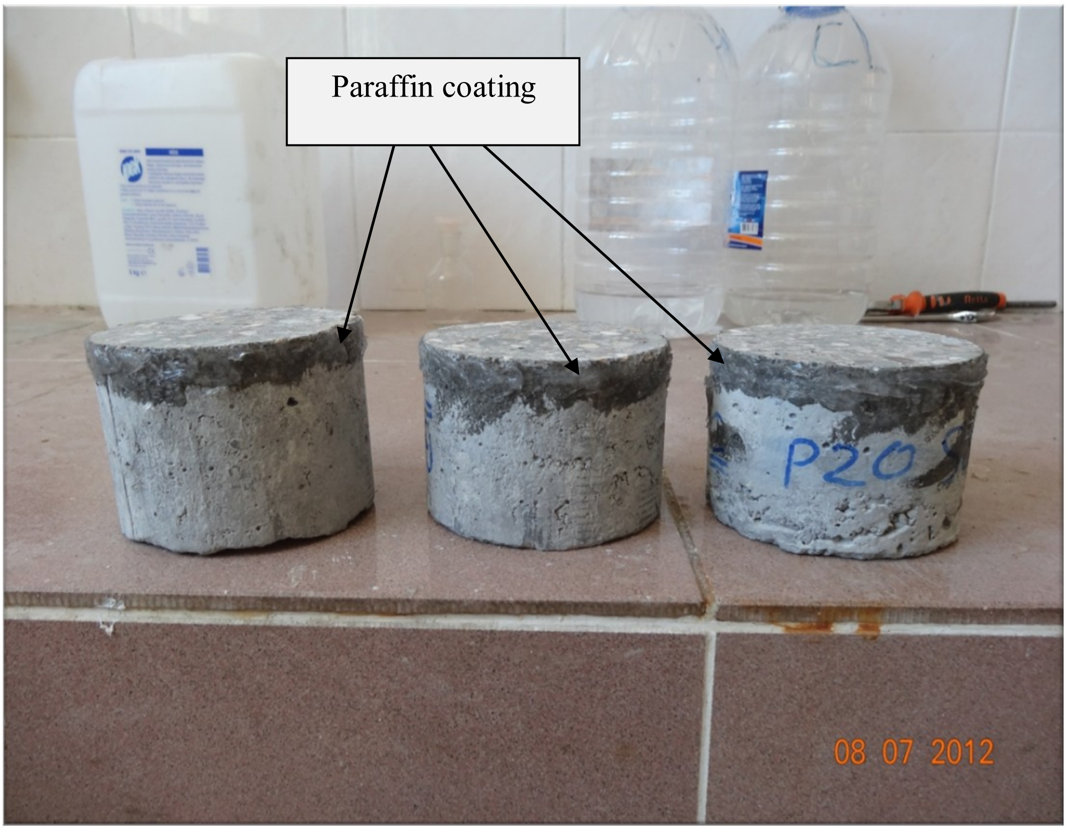


Figure 3.12 Photographic view of test specimens

Figure 3.13 Photographic view of sorptivity test

CHAPTER 4

TEST RESULTS AND DISCUSSIONS

4.1 Fresh Concrete Properties

The filling ability and stability of self-compacting concrete in the fresh state can be specified by the following critical properties: passing ability, viscosity, flowability, and segregation resistance, each of which being addressed through one or more test methods (EFNARC, 2005). Actually, flowability may be assessed by slump flow test while viscosity is determined via $T_{500\ mm}$ slump flow and V-funnel flow times. SCC requirements in the fresh state that are appropriate for a given application can be chosen from one or more of the above mentioned characteristics after being identified by class or target value given in Table 4.1 (EFNARC, 2005).

Table 4.1 Slump flow, viscosity, and passing ability classes with respect to EFNARC (2005)

Slump flow classes		
Class	Slump flow diameter [mm]	
SF1	550-650	
SF2	660-750	
SF3	760-850	
Viscosity classes		
Class	T_{500} [sec]	V-funnel time [sec]
VS1/VF1	≤2	≤8
VS2/VF2	>2	9 to 25
Passing ability classes		
PA1	≥0.8 with two rebar	
PA2	≥0.8 with three rebar	

4.1.1 Slump flow diameter

The test results on the fresh properties of SCCs were shown in Table 4.2 and Figure 4.1. The lowest slump flow diameter was measured for the control concrete (VP0S0) as 720 mm, while the mixture with 20% VP replacement (VP20S0) had the highest flow as 800 mm. Moreover, introduction of SF caused a down shift of the slump flow values for the same replacement levels of VP. The slump flow values of concretes incorporating SF varied between 710-760 mm. The replacement of cement by SF decreased the slump flow diameter as a result of more viscous behavior. The slump flow classes for SCCs without SF were SF2 for VP0SF0, while SF3 for VP0SF5, VP0SF10, and VP0SF20. On the other hand, SF incorporated ones were generally SF2 class except VP20SF8 (SF3). EFNARC specifies that the SCCs in SF2 class can be used for vertical applications in very congested structures, structures with complex shapes, or for filling under formwork. However, SF3 class SCCs will often provide better surface finish than SF2 for normal vertical applications but segregation resistance is more challenging to control.

Table 4.2 Slump flow diameter, slump flow time, V-funnel flow time and L-box height ratio properties of SCCs

	VP replacement level	Slump flow	$T_{500\text{ mm}}$	V funnel	L box
SF0	0	720	3.5	16.63	0.88
	5	770	2.47	16.47	0.91
	10	780	2.69	10.84	0.97
	20	800	2.25	8.27	1
SF8	0	710	3.72	23.97	0.85
	5	725	3.31	18.57	0.88
	10	740	2.4	13.25	0.91
	20	760	2.2	11.43	0.96

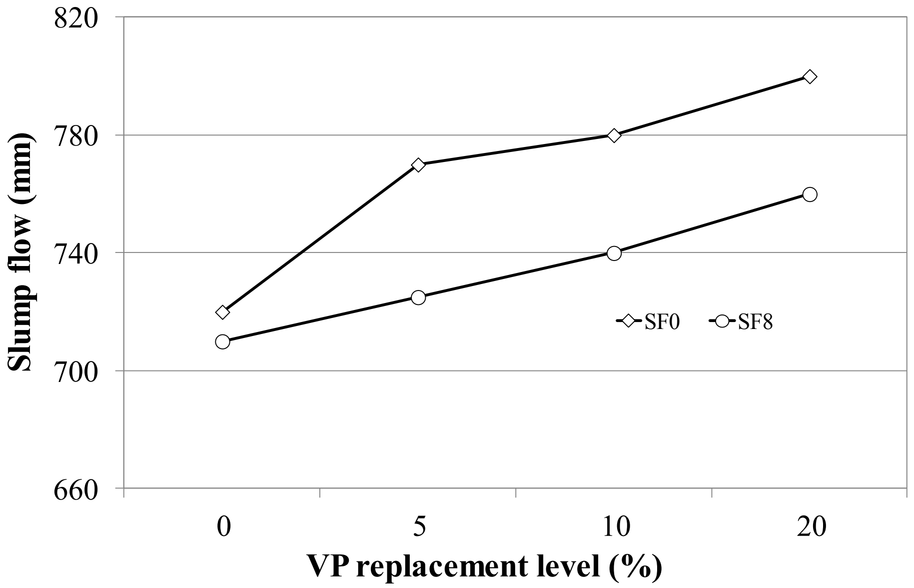


Figure 4.1.Variation of slump flow diameter with VP replacement

4.1.2 Slump flow and V-funnel flow times

The results of $T_{500\ mm}$ slump flow time showed that increasing the amount VP generally decreased the time required for SCC to reach 500 mm diameter (see Table 4.2). Although SF incorporated ones had a systematic decrease in slump flow time, VP10SF0 concrete showed a slight increase when compared to VP5SF0. Figure 4.2 indicates the variation of $T_{500\ mm}$ slump flow times of SCCs according to the replacement levels of VP and SF. Overall variation of the $T_{500\ mm}$ slump flow time was in the range 2.2 s and 3.72 s. V-funnel flow time reflects the viscosity and flowability of SCC. The results demonstrated that the tendency of V-funnel flow times were very similar to slump flow diameters.

Figure 4.3 demonstrates V-funnel flow times measured for SCCs. It was found out that 5% replacement level of VP was not so effective in reduction of V-funnel flow time of SF included SCC. However, increasing the amount of VP from 5% to 10%

and 20% resulted in sharp decrease. For example, 20% replacement level of VP resulted in 50% and 52% decrease in V-funnel flow times for SCCs with and without SF, respectively (see Figure 4.3).

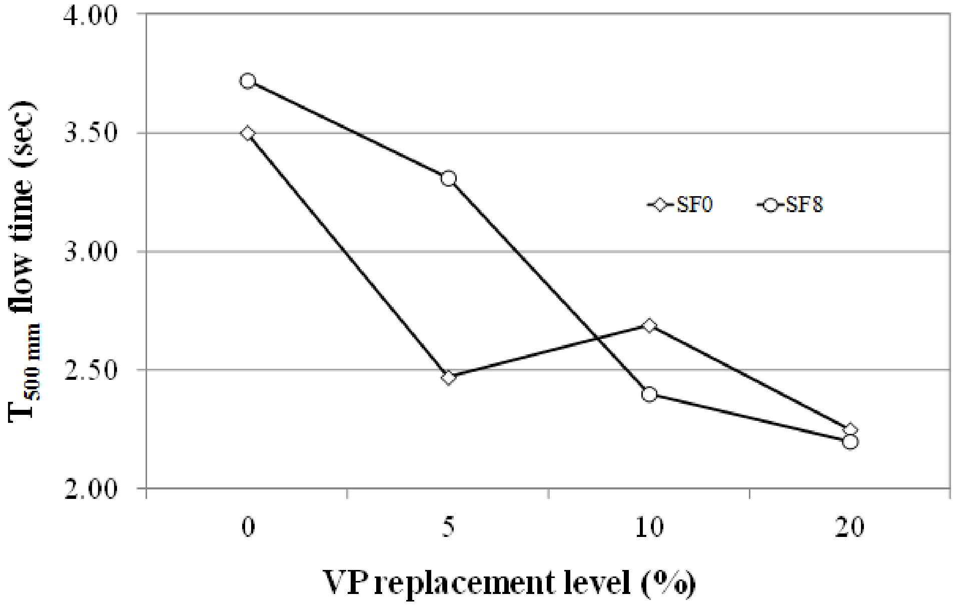


Figure 4.2.Variation of $T_{500\text{ mm}}$ with VP replacement

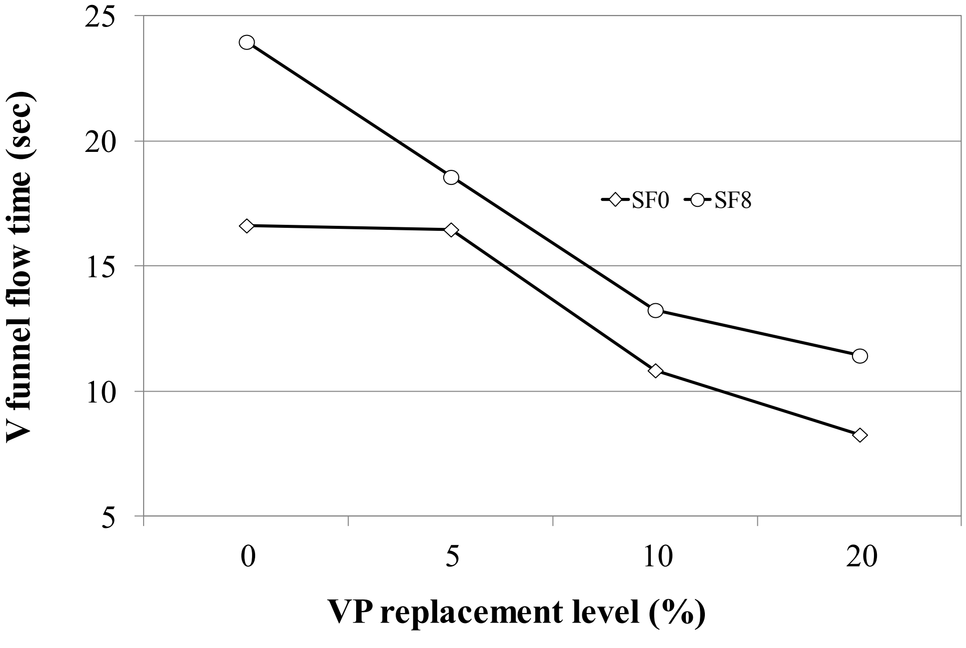


Figure 4.3 Variation of V-funnel time with VP replacement

When considering the interaction of slump flow and V-funnel flow times as shown in Figure 4.4, it was determined that all of the concretes were in the boundaries of VS2/VF2 viscosity class specified by EFNARC. It was also pointed out that such concretes might be helpful in limiting the formwork pressure or improving segregation resistance (EFNARC, 2005).

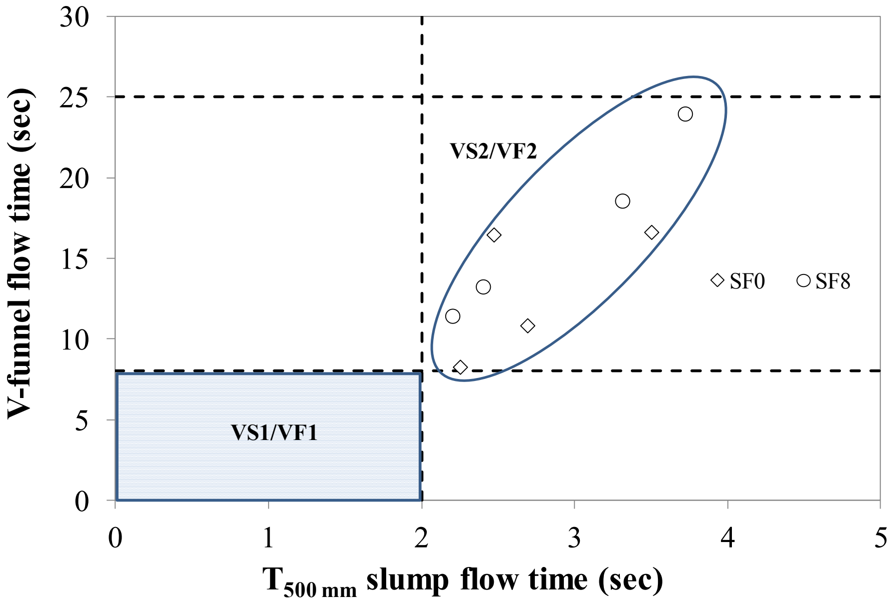


Figure 4.4 Variation of viscosity classes with $T_{500\ mm}$ slump flow and V-funnel flow times

4.1.3 L-box height ratio

To identify the passing ability of the produced SCCs, L-box height ratio was determined. The test provided H2/H1 ratio as a measure of the passing ability among the reinforcing bars. The variation in the three bar L-box height ratio is presented in Table 4.2 and graphically shown in Figure 4.5. To approve that a self-compacting concrete has an appropriate passing ability, L-box height ratio must be equal to or greater than 0.8. It should be noted that this ratio being 1.0 for perfectly fluid behavior of the concretes. The result was shown in Figure 4.5 that all of the mixtures satisfied the EFNARC limitation given for the L-box height ratio and increase in the replacement level of VP resulted in increase in the L-box height ratio to reach to 1. Although incorporation of SF inhibited the SCCs to reach height ratio of 1, the results presented proved that 8% SF incorporation was also yielded satisfactory results in terms of passing ability

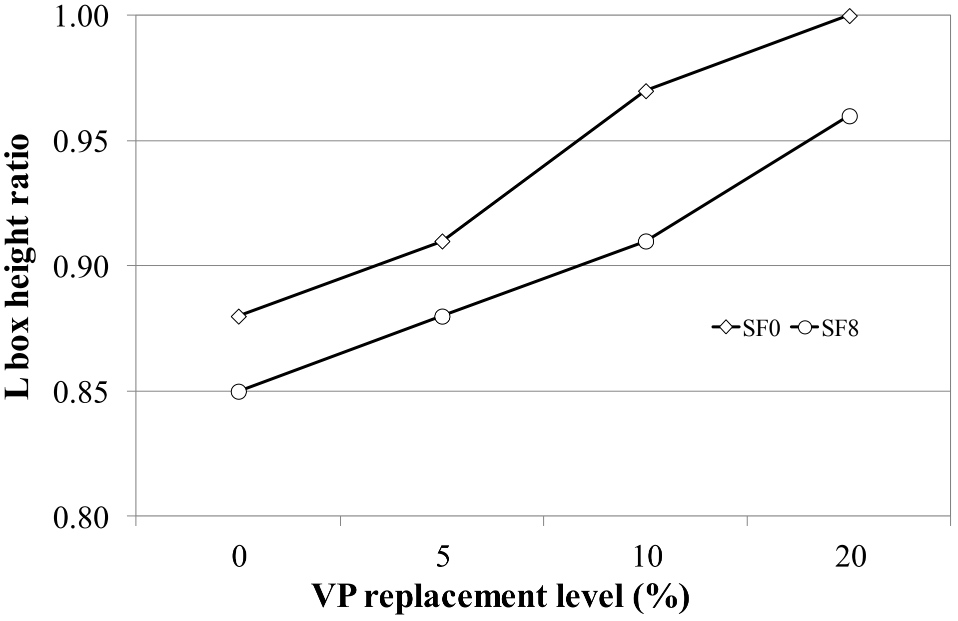


Figure 4.5 Variation of L-box height ratio with VP replacement

4.2 Hardened Properties

4.2.1 Compressive strength

The compressive strength test results were given in Table 4.3. Moreover, compressive strength developments of SCCs with and without SF incorporation over 90 days of moist curing were also demonstrated in Figures 4.6 and 4.7. Compressive strength of SCCs without SF varied between 30.4-72.3 MPa while the range of 30.0-81.9 MPa was obtained for SCC group incorporating SF. Increasing the amount of VP resulted in systematic decrease in compressive strength development while SF incorporation provided obvious enhancement at all ages. As can be seen from the figures that compressive strength development tendency of both groups seemed to be similar at early ages and 28 days without depending on the level of compressive strength. However, 90 day results revealed that the incorporation of VP resulted in more pronounced difference in compressive strength values. For example, 90 day compressive strength values of SCCs without SF varied between 68.9-72.3 MPa while the other series possessed the compressive strength values between 69.5-81.9 MPa mainly depending on VP replacement level.

The results have proved that later age compressive strength development of SCCs due to VP incorporation is more than that of early age development due to slow hydration mechanism. Like other natural pozzolan blended cement concretes, VP incorporated ones also requires prolonged curing period for effective contribution to the performance of the concrete. In the study of Güneyisi et al. (2011), it was revealed that natural pozzolan based blended cement mortars required longer curing time to gain relatively higher compressive strength than plain cement mortar. They reported that although lower compressive strength development rates for natural pozzolana blended cement mortars were measured at early ages (1, 3, and 7 days), the highest compressive strength values were obtained at later ages (90 and 180 days) at varying magnitudes depending on water-to-cement ratio.

Incorporation of volcanic pumice into concrete is known to have adverse effect on compressive strength of concrete, especially at early age. For example, in the study of Hossain (2003), volcanic pumice (VP) and volcanic ash (VA) was utilized up to 50% of the PC at varying levels. Production of the blended cements using volcanic ash and pumice was proposed. He reported up to 75% decrease in the compressive strength result was observed due to the incorporation of VP or VA.

Table 4.3 Compressive strength at different ages (MPa)

mix	3day	7day	28day	90day
Control mix	39.84	55.83	65.7	72.98
VP5S0	35.83	54.37	63.68	72.33
VP10S0	34.755	51.21	61.29	70.78
VP20S0	30.405	45.84	56.98	68.97
VP0S8	42.22	58.595	70.74	81.905
VP5S8	36.135	53.82	67.96	79.24
VP10S8	38	51.985	66.32	78.46
VP20S8	30.01	45.865	62.76	69.53

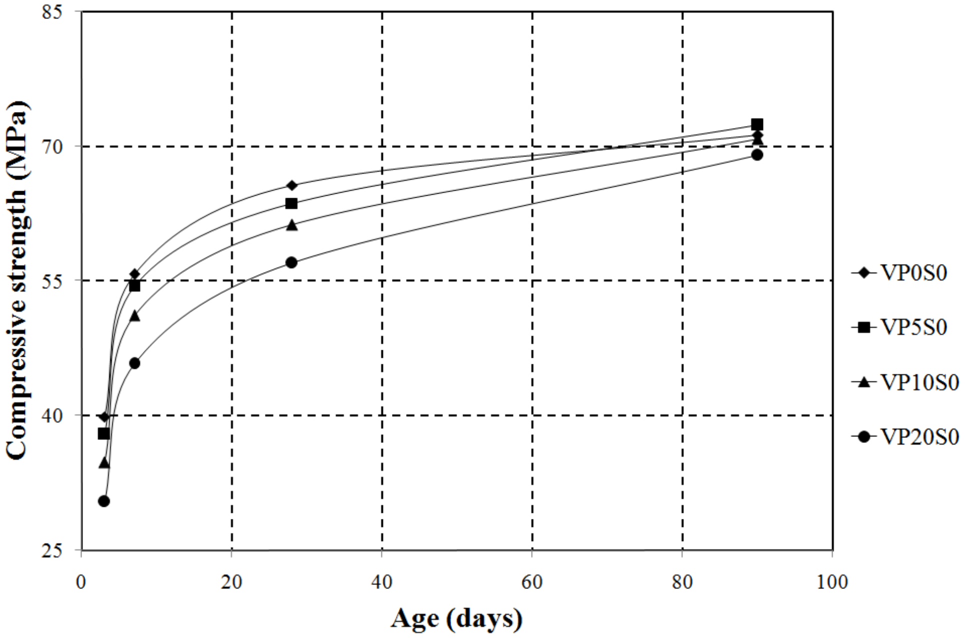


Figure 4.6 Compressive strength developments of SCCs without SF incorporation

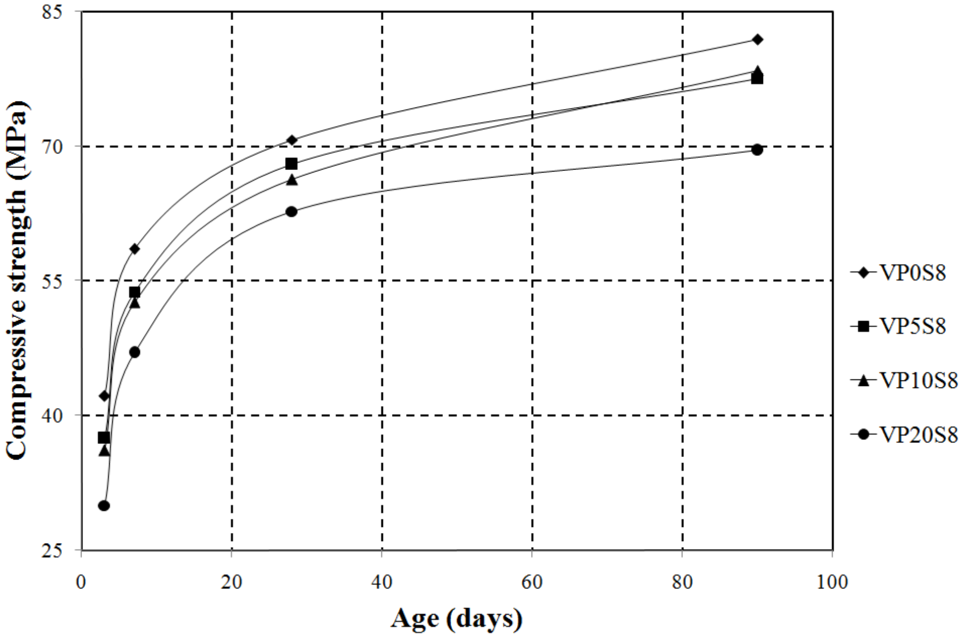


Figure 4.7 Compressive strength developments of SCCs with SF incorporation

4.2.2 Rapid chloride permeability

Rapid chloride permeability test (RCPT) per ASTM C1202 has been used by many researchers to characterize the chloride ion resistance of cement based materials. Table 4.4 shows the RCPT results and chloride permeability rating of SCCs according to ASTM C1202. Electrical indication of chloride permeabilities of SCCs in terms of total charge passed were graphically illustrated in Figure 4.8. The RCPT values ranged between 921-1582 Coulumbs and 443-1347 Coulumbs, for 28 and 90 days respectively. Figure 4.8a indicated that increasing the amount of VP up to 10% resulted in slight increases in 28 day RCPT values for SCCs with and without SF. However 90 day test results showed that the tendency of variation in RCPT values is to diminish as the amount of VP increases. Utilization of SF provided significant reduction in RCPT values at both age. The level of reductions were measured as 15-35% at 28 days and 43-59% at 90 days, mainly depending on the level of VP incorporation. Due to the fact that the minimum RCPT values were measured at 20% substitution of VP for both of the curing periods, it can be claimed that utilizing VP especially with ternary blends of SF may be an effective solution for the concrete structures to be used in chloride environments.

Based on ASTM C1202 classification it was determined that according to 28 day results all of the SCCs except VP20S8 were in "low chloride permeability" class while VP20S8 was in the "very low chloride permeability" class. However as a result of prolonged curing up to 90 days, all of the SCCs with SF were rated as "very low chloride permeability" concretes (100 Coulumbs<RCPT<1000 Coulumbs).

Hossain and Lachemi (2004) conducted a study on chloride diffusivity of volcanic ash blended cement mortar. They reported that mortars with 40% VA showed better performance in terms of chloride ion diffusivity and ingress. The reduction of chloride diffusivity was attributed to the fact that VA may have more amount of reactive alumina, which can adsorb more chloride ion to form Friedel's salts. Friedel's salt formation consequently lowers the levels of free chloride and hence reduces the chloride diffusivity of concrete. It was reported that volcanic ash (VA) and volcanic pumice have very similar compositions and are principally composed of silica content of about 60% (Hossain, 2005). Therefore, contribution of VP in enhancement of chloride permeability may be attributed to the facts mentioned above as well as filling effect due to higher specific surface area compared to Portland cement. However, the reason for the increase in RCPT values as a result of VP incorporation may be due to insufficient hydration due to the reduction of cement content.

Table 4.4 Chloride ion permeability values and ratings according to ASTM C1202

VP%	MIX.ID	28-day total charge (Coulumbs)	Rating	90-day total charge (Coulumbs)	Rating
0	VP0S0	1305.09	Low	1135.4	Low
5	VP5S0	1511	Low	1327.3	Low
10	VP10S0	1582	Low	1248.9	Low
20	VP20S0	1418.4	Low	1079.8	Low
0	VP0S8	1102	Low	643.64	Very low
5	VP5S8	1146.2	Low	640.67	Very low
10	VP10S8	1273	Low	472.46	Very low
20	VP20S8	921.33	Very low	440.73	Very low

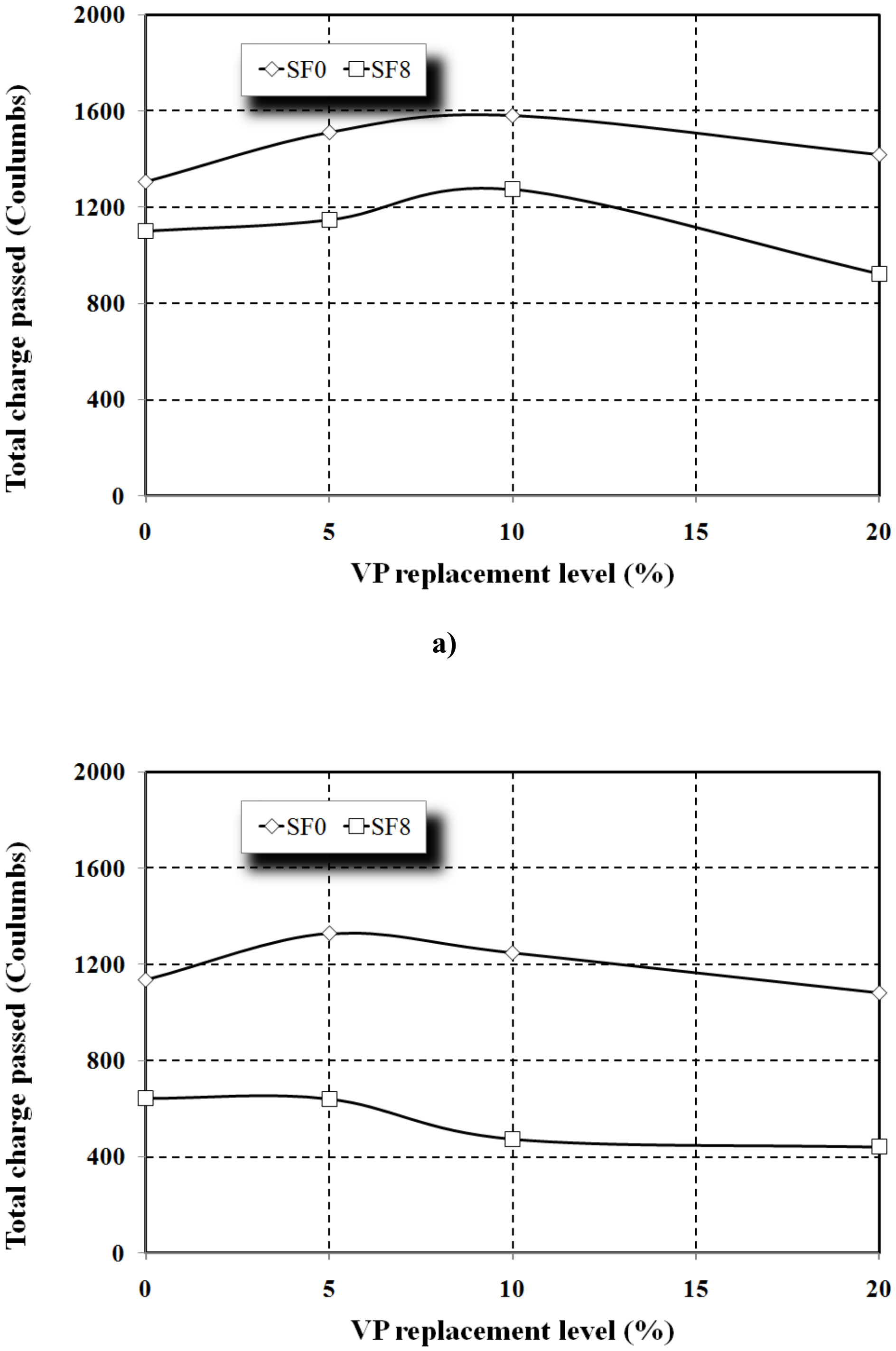


Figure 4.8 Variation of water absorption with replacement level of VP at

a) 28 days and b) 90 days

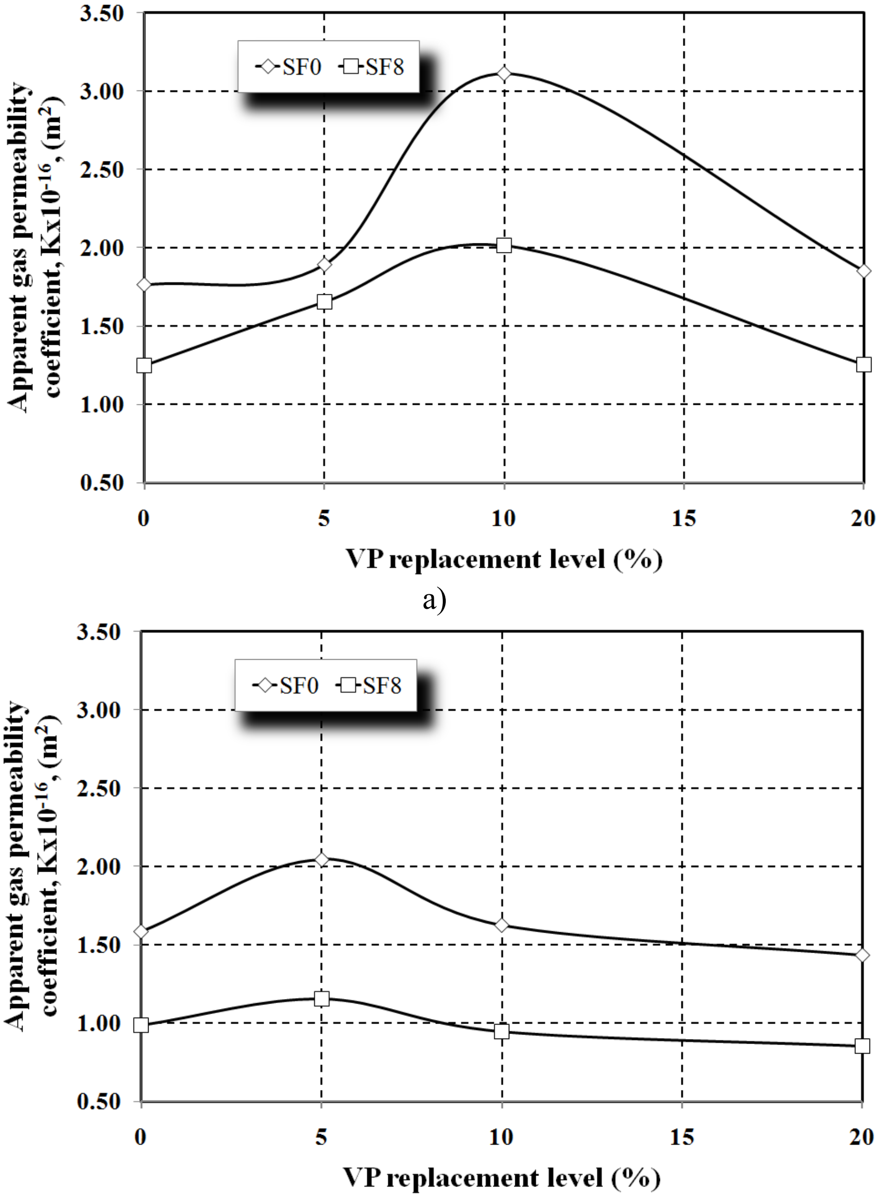
4.2.3. Gas permeability

Gas permeability coefficients obtained from average gas permeability values of 150, 200, and 300 kPa inlet pressure levels were graphically depicted in Table 4.5 and Figure 4.9 respectively. Figure 4.9a shows that 28 day gas permeability coefficients gradually increased due to utilization of VP up to 10% replacement level for SCCs with and without SF. However, 20% replacement level provided enhancement in gas permeability. The gas permeability coefficients obtained at this replacement level yielded almost same result as control concretes for both groups. This behavior may be attributed to filling effect of VP rather than its pozzolanic characteristics. However, 90 day gas permeability results revealed that improvement in gas permeability of concrete can be observed for the substitution levels of more than 5%. For example, when considering 28 day gas permeability of SCCs without VP, 10% replacement caused the values to increase by 76% and 62% for SCCs with and without SF, respectively. On the other hand, this replacement level provided negligible increase in gas permeability of the former, while slight improvement for the latter was observed at 90 days.

Effectiveness of incorporating SF can clearly be observed at both ages. Although the improvement in 28 days seemed to be slightly fluctuating, 90 day results revealed that the level of reductions are similar to each other at all of the substitution levels of VP. The lowest gas permeability coefficient was measured for VP20S8 concrete as 1.25 $x10^{-16}$ m^2 and $0.85x10^{-16}$ m^2 at 28 and 90 days, respectively. However, when observing strength development, VP replacement level of 20% caused significant reductions especially for the series with SF. The reason may be the formation of relatively lower strength, however, lower permeable matrix due to VP inclusion.

Table 4.5 Gas permeability coefficient values with VP replacement level

VP replacement (%)	28 days		90 days	
	without SF	with SF	without SF	with SF
0	1.76334	1.2462	1.5862	0.9864
5	1.896	1.6543	2.0468	1.154
10	3.1124	2.0134	1.6248	0.9475
20	1.8546	1.2543	1.4324	0.85476



a)

b)

Figure 4.9 Variation of gas permeability coefficient with replacement level of VP at

a) 28 days and b) 90 days

4.2.4 Water sorptivity and water absorption

The sorptivity test indicates the behavior of water transport through the pores of concrete due to capillary action. The sorptivity test results of all SCCs at different testing ages are shown in Table 4.6 and Figure 4.10. As it can clearly be observed from the figure that the sorptivity values at 28 and 90 days for the SCCs containing SF are obviously lower than the others. Since the pozzolanic reaction due to SF incorporation effectively diminishes the volume of pore space, the sorptivity gradually decreases as the curing period increases. However, pozzolanic property of VP is not as effective as SF such that increase in 28 day sorptivity values at 10% replacement level was observed. When observing 90 day sorptivity values VP incorporation seemed to be generally effective in reduction of sorptivity values.

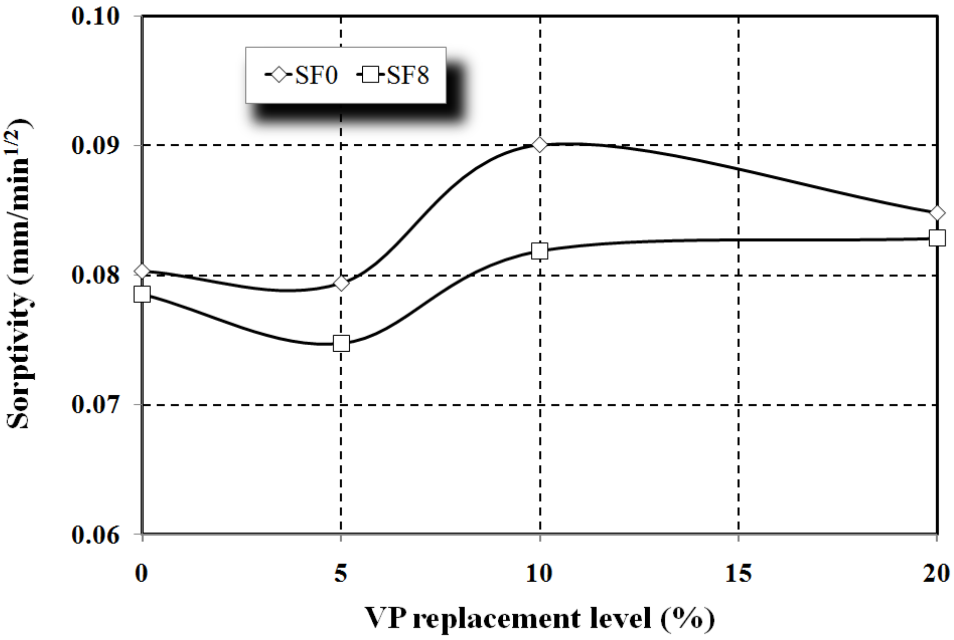
Water absorption test results were given in Table 4.7. Moreover, the test results were also plotted in Figure 4.11. When observing the tendency of water absorption values, similar trend can be observed in Figure 4.11. However, the variation in water absorption values of SCCs were not as high as sorptivity values, such that up to 14.0% and 6.7% variation in water absorption values at 28 and 90 days were observed, respectively, mainly depending on the composition of SCC. Absorption capacity of concrete can closely be correlated with the pore structure. Therefore, it can be inferred that 10% replacement level of VP caused slightly higher porosity at early ages than the other replacement levels. However, due to slow hydration mechanism, prolonged curing period provided the best performance in terms of water conductivity at this replacement level.

Table 4.6 Sorptivity values with VP replacement level

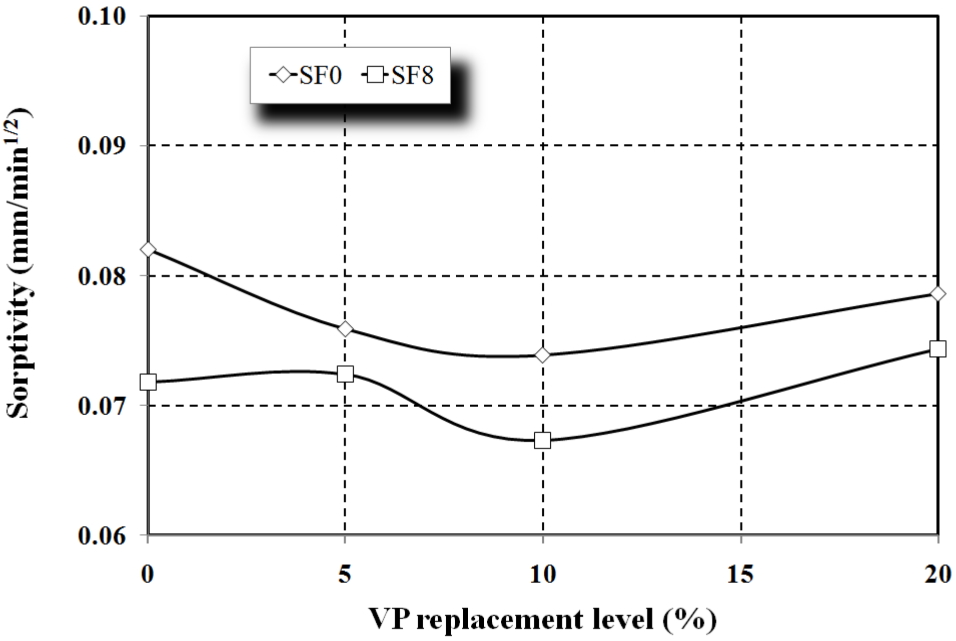
VP Replacement (%)	28 days		90 days	
	without SF	with SF	without SF	with SF
0	0.080267	0.0785	0.08205	0.0718
5	0.079367	0.0747	0.0759	0.0724
10	0.090033	0.081833	0.07385	0.067333
20	0.0848	0.082833	0.0786	0.074367

Table 4.7 Water absorption values with VP replacement level

VP Replacement (%)	28 days		90 days	
	without SF	with SF	without SF	with SF
0	5.110072	4.973013	4.216134	4.176803
5	5.27661	5.197976	4.435072	4.362327
10	5.670162	5.521599	4.233839	4.174471
20	5.442423	5.420743	4.330685	4.152613



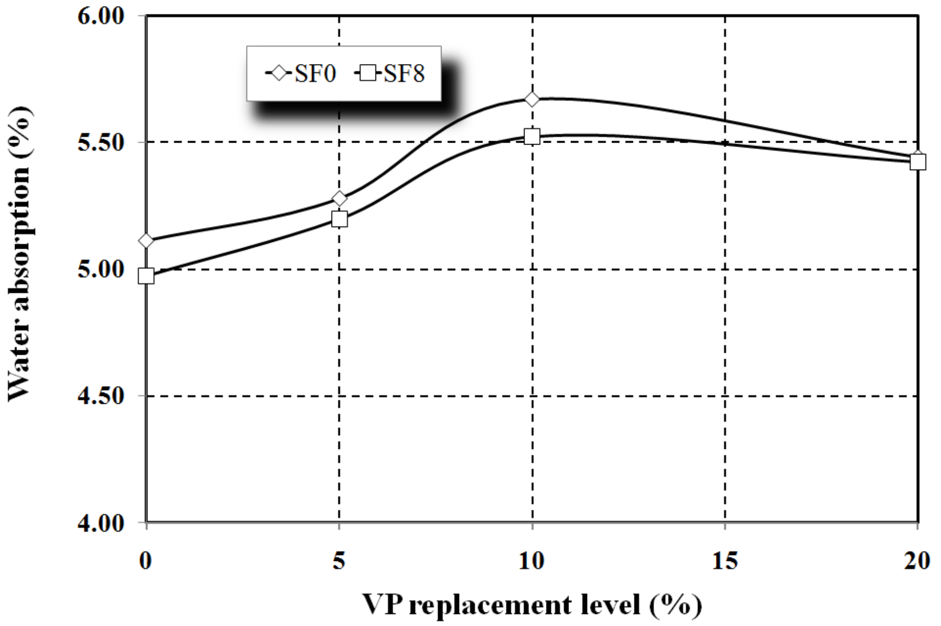
a)



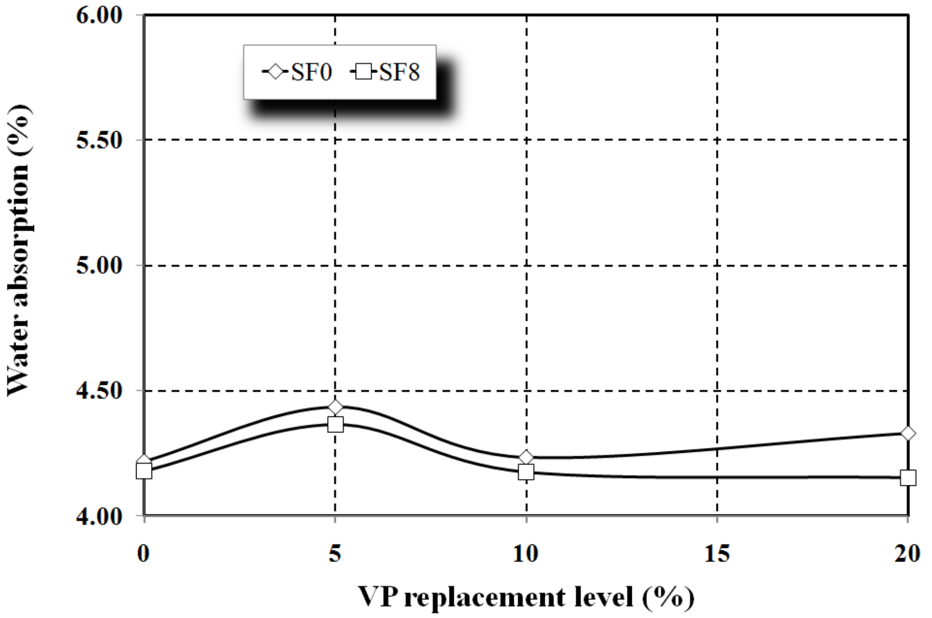
b)

Figure 4.10 Variation of water sorptivity with replacement level of VP at

a) 28 days and b) 90 days



a)



b)

Figure 4.11 Variation of water absorption with replacement level of VP at a) 28 days and b) 90 days

4.4. Statistical analysis

In order to assess the statistical significance of the experimental test parameters, general linear model analysis of variance (GLM-ANOVA) was performed at 0.05 level of significance. GLM-ANOVA is an important statistical analysis and diagnostic tool which helps in reducing the error variance and quantifies the dominance of a control factor.

To determine statistical significance of VP replacement levels and SF incorporation on the fresh properties GLM-ANOVA was applied and the results were presented in Table 4.8. In the analysis, VP replacement and SF were assigned as the independent variables while fresh properties were considered as the dependent variables. The general linear model analysis of variance was performed and the effective test parameters on the above mentioned properties were determined. As it can be seen in Table 4.8, the P-value of the parameters were less than 0.05, indicating that the variability of experimental test results can be effected in terms of test parameters. Therefore, it can be said that, type of VP replacement and SF are both statistically significant parameters affecting the variations of the slump flow diameter, and L-box height ratio. However, no statistical effectiveness was observed for $T_{500\ mm}$ slump flow time. This may be attributed to the narrowness of the range of the variation of the measured times. Table 4.8 also indicated that, although incorporation of VP significantly affected the variation of V-funnel flow times, 8% inclusion of SF was seemed to be statistically insignificant.

GLM-ANOVA was performed on the hardened properties and the effective test parameters such as compressive strength, RCPT, gas permeability, sorptivity, and water absorption for 28 and 90 days age respectively. The corresponding results were presented in Tables 4.9 and 4.10, respectively. It can be said that both of VP replacement level and SF inclusion are statistically significant parameters affecting the variations of the compressive strength and water absorption in 28 days. But no statistical effectiveness on sorptivity test was observed. On other hand, SF seemed to affect RCPT and gas permeability of SCCs at 28 days. This may be attributed to high reactivity and microfilling effects of SF even at early ages. Moreover, when considering GLM-ANOVA results presented in Table 4.10, it was found out that only inclusion of SF dominantly affected the variation of the hardened properties.

Table 4.8 Statistical evaluation of the test results for fresh properties

Dependent Variable	Independent variable	Sequential Sum of Squares	Mean Square	Computed F	P Value	Significance
Slump flow diameter	Addition of silica fume	33.81	2278.1	17.78	0.024	Yes
	Replacement level of pumice powder	66.19	1486.5	11.60	0.037	Yes
	Error	384.4	128.1			
	Total	7121.9				
Slump flow time ($T_{500\ mm}$)	Addition of silica fume	2.97	0.0648	0.55	0.513	No
	Replacement level of pumice powder	97.03	0.7057	5.96	0.088	No
	Error	0.3555	0.1185			
	Total	2.5376				
V-funnel flow time	Addition of silica fume	16.80	28.163	9.52	0.054	No
	Replacement level of pumice powder	83.20	46.450	15.70	0.024	Yes
	Error	8.877	2.959			
	Total	176.389				
L-box height ratio	Addition of silica fume	17.30	0.0032	32.00	0.011	Yes
	Replacement level of pumice powder	82.70	0.0051	51.00	0.005	Yes
	Error	0.0003	0.0001			
	Total	0.0188				

Table 4.9 Statistical evaluation of the test results for hard properties (28-days)

Dependent Variable	Independent variable	Sequential Sum of Squares	Mean Square	Computed F	P Value	Significance
Compressive strength	Addition of silica fume	50.652	50.652	270.13	0.000	Yes
	Replacement level of pumice powder	74.961	24.987	133.25	0.001	Yes
	Error	0.563	0.188			
	Total	126.175				
RCPT	Addition of silica fume	235971	235971	31.50	0.011	Yes
	Replacement level of pumice powder	84141	28047	3.74	0.153	No
	Error	22471	7490			
	Total	342583				
Gas permeability	Addition of silica fume	0.7553	0.7553	11.82	0.041	Yes
	Replacement level of pumice powder	1.4407	0.4802	7.52	0.066	No
	Error	0.19170	0.0639			
	Total	2.3877				
Sorptivity	Addition of silica fume	0.00003	0.00003	7.62	0.070	No
	Replacement level of pumice powder	0.00010	0.00003	7.29	0.068	No
	Error	0.00001	0.00003			
	Total	0.00001				
Water absorption	Addition of silica fume	0.0186	0.0186	10.87	0.046	Yes
	Replacement level of pumice powder	0.3455	0.1152	67.27	0.033	Yes
	Error	0.0052	0.0017			
	Total	0.3693				

Table 4.10 Statistical evaluation of the test results for hard properties (90-days)

Dependent Variable	Independent variable	Sequential Sum of Squares	Mean Square	Computed F	P Value	Significance
Compressive strength	Addition of silica fume	76.478	76.478	10.60	0.047	Yes
	Replacement level of pumice powder	73.535	24.512	3.40	0.171	No
	Error	21.651	7.217			
	Total	171.663				
RCPT	Addition of silica fume	841040	841040	118.79	0.002	Yes
	Replacement level of pumice powder	50900	16967	2.4	0.246	No
	Error	21239	7080			
	Total	913179				
Gas permeability	Addition of silica fume	0.9436	0.9436	91.30	0.002	Yes
	Replacement level of pumice powder	0.2234	0.0745	7.21	0.07	No
	Error	0.310	0.01			
	Total	10198				
sorptivity	Addition of silica fume	0.00008	0.00008	16.29	0.027	Yes
	Replacement level of pumice powder	0.00005	0.00002	3.65	0.158	No
	Error	0.00001	0.000005			
	Total	0.00014				
Water absorption	Addition of silica fume	0.0153	0.0153	7.94	0.067	Yes
	Replacement level of pumice powder	0.0535	0.1782	9.27	0.05	No
	Error	0.0058	0.0019			
	Total	0.0745				

CHAPTER 5

CONCLUSIONS

In this study, the binary and ternary effect of volcanic pumice powder and silica fume as supplementary cementing materials on the fresh properties and strength of SCC was investigated. Based on the results of the experimental study presented above, the following conclusions may be drawn:

1. The volcanic pumice powder replacement of cement was proved to be applicable in self compacting concrete production without any segregation and bleeding. Even at the most extreme level of replacement (20%), SCC without loss of uniformity and stability was produced.
2. It was observed that increasing the replacement level of VP resulted in increase in the flowability of SCC mixtures, even when SF was added the flowability the level of effectiveness of VP seemed to have same trend. A similar trend was also observed in the $T_{500\ mm}$ and V-funnel flow times of the SCCs. All mixtures were observed to be in viscosity class of VS2/VF2 class.
3. It was observed that increasing the replacement level of VP resulted in a gradual increase in the L-box height ratio of SCCs mixes. Moreover, the height ratio reached to 1.0 for the mixtures with 20% replacement of VP, revealing the highest fluid behavior.

4. A systematic decrease in compressive strength of the concretes was observed with increasing the percentage of VP. The addition of SF compensated the reduction in compressive strength. Moreover, SF incorporated SCCs revealed better compressive strength development than that of other group.
5. When VP was used as a cement replacement material, the chloride resistances of concretes were at similar level (low rate) especially at 90 days curing. Moreover as a result of SF incorporation the chloride permeability ratings of SCCs were observed to be "very low" according to ASTM C1202.
6. Gas permeability and sorptivity tests reflect the permeability characteristics of the concretes. Lower permeability of the concretes can be directly related to enhanced durability. The concretes with higher content of VP appeared to have relatively lower gas permeability coefficients. Similar to the behaviour observed for chloride ion permeability, increasing VP content resulted in gradual variations in sorptivity coefficients. Besides SF inclusion provided significant improvement in transport properties especially at later ages. Therefore it may be concluded that in SCC production, increasing amount of VP up to 20% together with utilizing SF might be a good solution for the concretes exposed to severe chemical attack.
7. Statistical analysis has revealed that incorporation of VP and SF was observed to be statistically significant on slump flow diameter, L-box height ratio, for fresh concrete properties and, 28 day water absorption. However, V-funnel flow time, 28 day sorptivity and 90 water absorption was not affected from the inclusion of SF. Since the variation of slump flow time ($T_{500\ mm}$) was in narrow range, both of the mineral admixtures seemed to have statistically insignificant effects.

8. The benefits of utilization of natural pozzolana such as VP is not limited to enhancement in concrete properties, but also reduction of cement content provides cost saving and less pollution due to cement manufacturing process. Hence, this study revealed that production of green SCCs with acceptable performance level is possible through beneficiation of VP as a supplementary cementitious material.

REFERENCES

AASHTO T277. (2007). Standard Method of Test for Rapid Determination of the Chloride Permeability of Concrete.

Alexander, M.G. and Magee, B.J. (1999). Durability performance of concrete containing condensed silica fume. *Cement and Concrete Research*, **29**, 917-922.

Alshamsi, A.M., Sabouni, A.R., and Bushlaibi, A.H. (1993). Influence of set retarding superplasticizers and micro-silica on the setting times of pastes at various temperature. *Cement and Concrete Research*, **23**,592–598.

American Concrete Institute. (1993). *Application of super workable concrete to reinforced concrete structures with difficult construction conditions ACI Report SP- 140*. Detroit: Mlura, N., Akeda, N., Chlkamatsu, R. and Sogo, S.

American Concrete Institute. (1995). *Ground Granulated Blast-Furnace Slag as a Cementitious Constituent in Concrete.* ACI 233R-95.

American Concrete Institute. (1996). *Guide for the Use of Silica Fume in Concrete*. ACI 234R-96.

American Concrete Institute.(1996). *Use of Fly Ash in Concrete*. ACI 232.2R-96.

ASTM C39. (2010).Standard test method for compressive strength of cylindrical concrete specimens. *Annual Book of ASTM Standards*

ASTM C1202, (1993) Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration, *Annual Book of American Society for Testing Materials Standards*, Vol. C04.02.

ASTM C150, (2005) American Society for Testing and Material, West Conshohocken

ASTM C 1240-97, (1997) Standard specification for silica fume for use as a mineral admixture in hydraulic-cement concrete, mortar and grout.

ASTM C 618-91, (1991) Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete," ASTM International, West Conshohocken, Pa., 4 pp.

Azmar , (2003). Pure Natural Pozzolana Cement; a Better Alternative. Report of Azmar International works Pagan Island Natural Pozzolans, Texas, and United States of America.

Brandt, M.Andrzej,(2009),Cement-Based Composites, Second Edition, New York.

Bentz D.P., Stutzman P.E.,(1994) Evolution of porosity and calcium hydroxide in laboratory concretes containing silica fume, *Cement and Concrete*. **Res. 24** 1044– 1050.

Bhanja, S. and Sengupta, B. (2005). Influence of silica fume on the tensile strength of concrete. *Cement and Concrete Research*, **35**, 743-747.

Bhatty, J. I. (1995) “Role of Minor Elements in Cement Manufacture and Use”, Research and Development Bulletin RD109T, *Portland cement Association*, Skokie, Illinois, pp.1-35.

Bilgen, G.; Kavak, A.; Yıldırım, S.T.; and Çapar, O.F. (2010). Blast furnace slag and its importance in the construction sectors. *The Second National Solid Waste Management Conference,* .**578**, Mersin, Turkey.

Brooks, J.J., Megat, J.M.A., and Mazloom, M. (2000). Effect of admixtures on the setting time of high-strength concrete. *Cement and Concrete Composites,* **22**, 293–301.

Cabrera, J.G. (1986). The use of pulverized fuel ash to produce durable concrete Institute of Civil Engineering in Improvement of Concrete Durability, 29-59.

Carette, G.G., and Malhotra, V.M. (1983). Mechanical properties, durability, and drying shrinkage of Portland cement concrete incorporating silica fume. *Cement, Concrete, and Aggregates,* **5**, 3-13.

Dadu, D. W. (2011) “Jos Plateau Volcanic Deposits as Sustainable Cementitious Materials for Partial Replacement of Portland Cement” In Laryea, S., Leiringer, R. and Hughes, W. (Eds) *Procs West Africa Built Environment Research (WABER) Conference,* 19-21 July 2010, Accra. pp. 691-701.

Day, R. L., (1990), Pozzolans for Use in Low Cost Housing. In: Report Prepared for *the International Development Research Centre*, September, 1990, Ottawa.

De Almeida, I.R. and Gonvalces, A.F. (1990). Proceedings of the RILEM colloquium on properties of fresh concrete. In H.J. Wierig (ed.). *Properties of freshly mixed high-strength concrete.*

Detwiler, R. J., Bhatty J. I. and Bhattacharja S (1996) “Supplementary Cementing Materials for Use in Blended Cements”. *In; Research and Development Bulletin*, Portland cements Association.

Domone, P.L. (2007). A review of the hardened mechanical properties of self compacting concrete. *Cement and Concrete Composites*, **29** (1), 1-12

Econoler International (2009) “Cement Sector Programme in Sub- Saharan Africa: Barrier to Clean Development Mechanism Project Development in Africa’s Cement” .In; report to World Bank Carbon Finance Assistance, April. Retrieved from www.econolerinter.com, pp.1-135.

EFNARC. (2005). Specification and guidelines for self compacting concrete. *Available at* *http://www.efnarc.org*.

Erdoğan, T.Y.(1997). Admixture for *Concrete.METU Press*, Ankara, Turkey.

EUROPEAN STANDARD EN 197-1.

European Commission (2001). Pollution Control on Best Available Techniques in the Cement and Lime Manufacturing Industries. *In European Commission Report,* pp. 10-14, Seville, Spain.

FHWA,(2005), U.S. Department of transportation, Federal Highway administration, Silica fume user's manual,05-016.

Gagne. R. Pigeon. M. and Ai'tcin. P. C. (1989). "Deicer salt scaling resistance of high performance concrete." Paid Klieger Symposium on Performance of Concrete, SP-122. ACI.

Gesoğlu, M., Özbay, E. (2007). Effects of mineral admixtures on fresh and hardened properties of self-compacting concretes: binary, ternary and quaternary systems. *Materials and Structures*, **V.40**, pp.923-937.

Gesoğlu, M. and Özbay, E. (2007). Effects of mineral admixtures on fresh and hardened properties of self-compacting concretes: binary, ternary and quaternary systems. *Materials and Structures*, **40(9)**, 923-937.

Gopalan, M. K., and Haque, M. N., (1987) "Effect of Curing Regime on the Properties of Fly-Ash Concrete," *ACI Materials Journal*, V. **84**, No. 1, pp. 14-19.

Gündüz L, Sariisik A, Tozacan B, Davraz M, Ugur I, Cankiran O (1998). Pumice Technology" *Isbas A. S. and Sdu College Of Engineering*, **vol: 1**, Isparta, Turkey.

Güneyisi, E. (2004). Mechanical and durability performance of plain and blended cement concrete exposed to chlorides and different curing regimes. PhD thesis, Bogazici *University, Istanbul.*

Güneyisi, E.; Gesoğlu, M., (2011) Properties of self-compacting Portland pozzolana and limestone blended cement concretes containing different replacement levels of slag, *Materials and Structures*, V. **44**, p. 1399 - 1410.

Grunewald, S, Walraven, J. C. (2001). Parameter-Study on the Influence of Steel Fibres and Coarse Aggregate Content on the Fresh Properties of Self-Compacting Concrete. *Cement and Concrete Research*, **V.31**, pp.1793–1798.

Hayakawa, M., Kuroiwa, S., Matsuoka, Y. and Shindoh, T. (1993) Application of super workable concrete to construction of a 20-storey building, *High Performance Concrete in Severe Environments,* Ed. Paul Zia, ACI SP-**140**, pp. 147–161.

Helland, S., Hoff, A. and Einstabland, T. (1983). High strength concrete. Presented at *Norsk Betongdag, Trondheim, Norway*.

Holton I. (2004). Self-compacting concrete.BRE information Paper. Report *IP 3/04, British Research Establishment,* Watford, UK.

Horst, S. (2001) "Some Basics about Substituting Pozzolans for Portland cement in Concrete"; *In: Proc at the Council of United States of America Green Building Council Summit held* at Tucson, Arizona.

Hossain M.A.K and Mohamed Lachemi (2006) Development of Volcanic Ash Concrete: Strength, Durability, and Microstructural, *ACI material journal*, no.103-M02

Hossain K.M.A.(1999) , Performance of volcanic ash concrete in marine environment, Proceedings of 24th OWICS Conference, ''2*1st Century Concrete and Structures*'', Singapore, vol. XVIII, , pp. 209– 214.

Hossain K.M.A.,(1999) Properties of volcanic ash and pumice concrete, *IABSE Report* **81** 145–150.

Hossain K.M.A.,(2004) Properties of volcanic pumice based cement and lightweight concrete, *Cement and Concrete. Res*. **34** (2) 283– 291.

Hossain K.M.A., M. Lachemi,(2004) Corrosion resistance and chloride diffusivity of volcanic ash blended cement mortar, *Cement and Concrete Res*. **34** (4) 695–702.

Hossain, A.K.M., Narum Nabi, Iyanatu Islam, (2005), Bangladesh's Development Agenda and Vision 2020, **17**, 708-709.

Hossain K.M.A. (2003). Properties of volcanic pumice based cement and lightweight concrete, *Cement and Concrete Research*, **34**: 283-291.

http://www.silicafume.org/general-silicafume.html.

http://www.vitechvn.com.vn

JSCE (1999)"*Recommendation for Self Compacting Concrete*" Tokyo: Japan Society of Civil Engineers, Concrete Engineering Series 31.

Kosmatk, S., Kerkhoff, B., and Panerese, W., (2002), Design and Control of Concrete Mixtures,14th Edition, Portland Cement Association, Skokie, Illinois.

Khayat, K.H., Manai, K. and Trudel, A. (1997). In situ mechanical properties of wall elements cast using self consolidating concrete. *ACI Materials Journal*, **V.94**, pp.492-500.

Khedr, S.A., and Abou-Zeid, M.N. (1994). Characteristics of silica-fume concrete.Journal of *Materials in Civil Engineering*, **6,** 357–375.

Kuder, K.G., Özyurt, N., Mu, E.B., and Shah, S.P. (2007). Rheology of fiberreinforced cementitious materials. *Cement and Concrete Research*, **37**,191–199

Kurokawa, Y., Tanigawa, Y., Mori, H., and Nishinosono, K. (1996). Analytical Study on Effect of Volume Fraction of Coarse Aggregate on Bingham's Constants of Fresh Concrete. *Transactions of the Japan Concrete Institute*, **V.18**, pp.37–44.

Kurtis, K. (2002), Supplementary Cementitious Materials. In*: Pres to Precast Concrete Association,* PCA CD 2038.

Lachemi, M., Hossain, K.M.A., Lambros, V., Nkinamubanzi, P.C., and Bouzoubaa, N. (2004). Performance of new viscosity modifying admixtures in enhancing the rheological properties of cement paste. *Cement and Concrete Research*, **34** (2), 185–193

Maekawa, k., and Ozawa, k., (1999) "development of SCC's prototype" (written in Japanese), *Self Compacting High Performance Concrete*, Social System Institute,20-32

Malhotra, V.M. (1986). Superplasticizer fly ash concrete for structural applications. *Concrete International*, **8**, 28–31.

Mazloom, M., Ramezanianpour, A.A. and Brooks, J.J. (2004). Effect of silica fume on mechanical properties of high-strength concrete. *Cement and Concrete Composites*, **26**, 347-357

Mehelcic, R. (2003) "Development of Appropriate and Sustainable Construction Materials, *Michigan Technology University".* Retrieved on August 4th 2008 from: www.mtu.edu pp1- 17.

Mishima, N., Tanigawa, Y., Mori, H., Kurokawa, Y., Terada, K., Hattori, T. (1999). Study on Influence of Aggregate Particle on Rheological Property of Fresh Concrete. *Journal of the Society of Materials Science*, **V.48**, pp.858–863.

Nagamoto N, Ozava K. (1997). Mixture properties of self-compacting concrete. *In Proceedings of third CANMET/ACI International Conference on design and materials and recent advances in concrete technology*, ACI SP **172**, Kuala Lumpur, American Concrete Institute, MI, USA: Farmington Hills, pp. 623–37.

Naik, T. R. (2005) "Sustainability of Cement and Concrete Industries; Global Construction", Dundee, Scotland

Neville, A. M. (1996). Properties of Concrete. *John Wiley and Sons,* New York.

Okamura, H. (1997). Self-compacting high performance concrete, *Concrete International*, **19**, 50–54

Okamura H, Onchi M. (1999). Self-compacting concrete: development, present use and future. *In Proceedings of First International Conference on Self-Compacting Concrete*, Stockholm, pp.13–14.

Okamura, H., Ouchi, M., Self compacted concrete, 2003, *Journal of Advanced Concrete Technology,* **1(1)**, 5–15.

Okamura, H., Maekawa, K., and Ozawa, K. (1993). High Performance Concrete. Tokyo: *Gihoudou Press*.

Okamura, H, Ozawa, K., Sakata, N., (1995), "Evaluation of Self-Compactability of Fresh Concrete Using the Funnel Test," *Concrete Library of JSCE* (**25**) June 1995.

Ozawa, K., Maekawa, K., Kunishima, M., and Okumura, H. (1989) Proceedings of the second East-Asia and Pacific Conference on the Structural Engineering and Construction (EASEC-2). *Development of High performance concrete based on the durability design of concrete structures.*

Özbay Erdogan. (2007). Effects of Mineral Admixtures on the Fresh and Hardened Properties of Self Compacting Concretes: Binary, Ternary, and Quaternary Systems, *Gaziantep University.*

Park, C.K., Noh, M.H., and Park, T.H. (2005). Rheological properties of cementitious materials containing mineral admixtures. *Cement and Concrete Research*, **35**, 842–849

Persson, B. (2001). A comparison between mechanical properties of self-compacting concrete and the corresponding properties of normal concrete. *Cement and Concrete Research***,** **31**, 193-198.

Picandet V, Khelidj A, Bastian G.(2001). Effect of axial compressive damage on gas permeability of ordinary and high-performance concrete. *Cement and Concrete Research*, **V.31**, pp.1525–1532.

Pigeon, M , Aitcin, P-C, Pleau, R, (1986), Freeze-Thaw Durability of Concrete With and Without Silica Fume in ASTM C 666 (Procedure A) Test Method: Internal Cracking Versus Scaling, V**.8**, pp10

Pistilli, M.F., Wintersteen, R., Cechner, R. (1984). The uniformity and influence of silica fume from a U.S. source on the properties of Portland cement concrete. *Cement, Concrete and Aggregates*, **6**, 120–124.

Precast/Prestressed Concrete Institute Interim SCC Guidelines FAST Team (April 2003)," *Interim Guidelines for the Use of Self-Consolidating Concrete*".

R.F. Feldman, C.Y. Huang, (1985) Properties of Portland cement– silica fume pastes: I. Porosity and surface properties, *Cement and Concrete Res.* **15** 765–774.

RILEM TC 116-PCD.(1999).Permeability of concrete as a criteron of its durability. *Materials and Structures journal*.V.**32**, pp.174-179.

Sakata, S., Maruyama, K., and Minami, M. (1996). Proceedings of RILEM International conference production methods and workability of Concrete. In: P.J.M. Bartos, D.L. Marrs, and D.J. Cleland (Eds.), *Basic properties and effects of welangum on self compacting concre*te. London: E&FN Spon, 1–24

Samarin, A., and Ryan, W. G., (1975) "Experience in Use of Admixtures in Concrete Containing Cement and Fly Ash," Workshop on the Use of Chemical Admixtures in Concrete, University of New South Wales, Kensington, pp. 91-112.

Sari, M; Prat, E; and Labastire, JF.(1999). High strength self compacting concrete: original solutions associating organic and inorganic admixtures. *Cement and Concrete Research*,**V.29**, ,pp.813–818

Saric-Coric, M.; Khayat, K. H.; and Tagnit-Hamou, A. (2003). Performance Characteristics of Cement Grouts Made with Various Combinations of High-Range Water Reducer and Cellulose-Based Viscosity Modifier. *Cement and Concrete Research*, **V. 33**, No. 12, pp. 1999-2008.

Scali,M.J., Chin, D., and Berke, N.S. (1987). Proceedings of ninth international conference on cement microscopy. Effect of Micro silica and Fly Ash upon the Microstructure and Permeability of Concrete. *International Cement Microscopy Association*, Duncanville, Texas.

Sellevold, E.J. and Nilsen, T. (1987). Supplementary Cementing Materials for Concrete. In V.M. Malhotra (ed.). *Condensed Silica Fume in Concrete*.

Sonebi M. (2004). Medium strength self-compacting concrete containing fly ash modeling using factorial experimental plans. *Cement and Concrete Research,* **V.34**, pp.199–208.

Shetty, M. S. (2005) "Concrete Technology; *Theory and Practice*", S Chad and Company,New Delhi, India, pp. 124-238.

Shindoh, T., Matsuoka, Y., Sakamoto, J., and Tangermsirikul, S., (1990) "*Properties of Super Workable Concrete in Fresh State" Proceedings of the 45th Annual Conference of Japan Society of civil Engineers*, **5**,228-229.

Shindoh, T.; Mastuoka, Y., (2003) Development of a Combination-Type Self-Compacting Concrete and Evaluation Testing Methods, *Journal of Advanced Concrete Technology,* V. **1**, No. 1, p. 26-36.

Su, N., Hsu, K.C. and Chai, H.W. (2001). A simple mix designs method for self compacting concrete. *Cement and. Concrete Research*, **V.31**, No.12, pp.1799-807.

Tanaka, M., Mori, K., and Shindoh, T. (2001)"Application of Self Compacting Concrete to Steel Segments of Multi-Micro Shield Tunneling Method" *Proceedings of the Second International Symposium on Self Compacting Concrete*, Tokyo 2001. Coms Engineering Corporation, 651-660

Wee T.H. , J. Zhu, H.T. Chua, S.F. Wong, Resistance of blended cement pastes to leaching in distilled water at ambient and higher temperatures, *ACI Mater*. **J. 98 (2)** (2001) 184–193.

Wild, S., Sabir, B.B. and Khatib, J.M. (1995). Factors influencing strength development of concrete containing silica fume. *Cement and Concrete Research*, **25,**1567–1580

Yıldız, K. and Ugur, L.O. (2009).The effect of mineral admixture type on the modulus of elasticity of high strength concrete*, Scientific Research and Essay* Vol.**4** (8), pp. 791-798

Zhang M.H. , O.E. Gjorv,(1991) Effect of silica fume on pore structure and chloride diffusivity of low porosity cement pastes, *Cement and Concrete.* ***Res.*** **21** 1006– 1014.