UNIVERSITY OF GAZIANTEP
GRADUATE SCHOOL OF
NATURAL AND APPLIED SCIENCES

AN EXPERIMENTAL STUDY ON THE WORKABILITY OF CARBON FIBER REINFORCED SELF-COMPACTING CONCRETE

M.Sc. THESIS
IN
CIVIL ENGINEERING

BY
GHAZALA YOUNUS ASAAD
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Supervisor:

Assoc. Prof. Dr. Erhan GÜNEYİSİ

By
Ghazala Younus ASAAD
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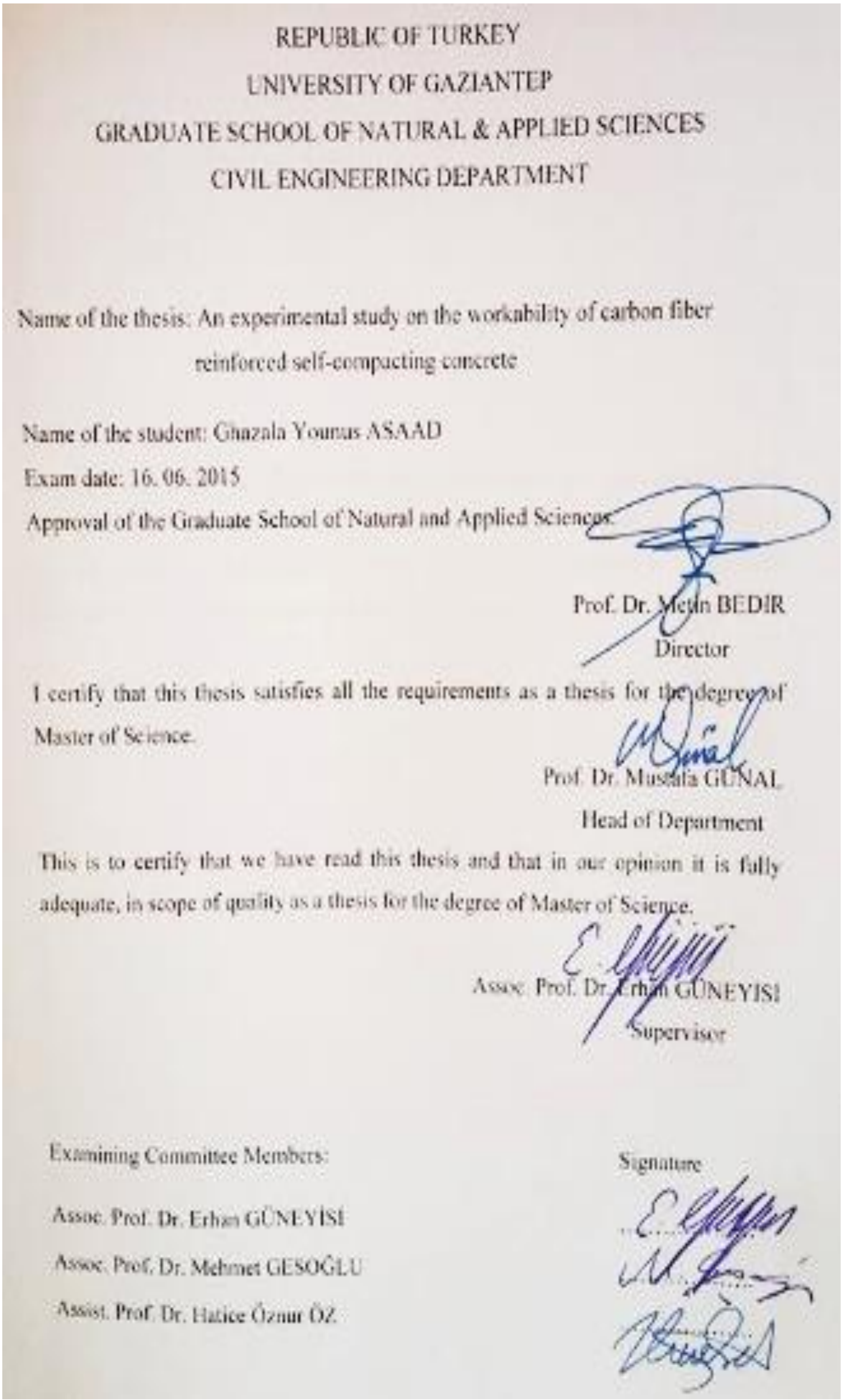

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Prof. Dr. Metin BEDIR
Director

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 of quality as a thesis for the degree of Master of Science.

Assoc. Prof. Dr. Erhan GÜNEYISI
Supervisor

Examining Committee Members:	Signature
Assoc. Prof. Dr. Erhan GÜNEYİSİ	....
Assoc. Prof. Dr. Mehmet GESOĞLU	....
Assist. Prof. Dr. Hatice Öznur ÖZ	....

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Ghazala Younus ASAAD

ABSTRACT

AN EXPERIMENTAL STUDY ON THE WORKABILITY OF CARBON FIBER REINFORCED SELF-COMPACTING CONCRETE

ASAAD, Ghazala Younus

M.Sc. in Civil Engineering
Supervisor: Assoc. Prof. Dr. Erhan GÜNEYİSİ
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This study aimed to experimentally investigate the effect of carbon fiber volume fraction and silica fume on the fresh properties of self-compacting concrete. For this, two different self-compacting concrete series were manufactured in this study. First self-compacting concrete series was produced without silica fume while the second series was manufactured with 10% silica fume by weight of total binder content. In both self-compacting concrete series, the total binder content and water-to-binder ratio was kept constant as 530 kg/m^3 and 0.37, respectively. Besides, Portland cement was substituted with fly ash at the level of 30% by weight. Moreover, to explore the effect of carbon fiber content, four carbon fiber volume fractions of 0%, 0.5%, 1.0%, and 1.5% were considered in this study. In total, eight carbon fiber reinforced self-compacting concrete mixtures were designed. The fresh properties of self-compacting concrete mixtures were evaluated in terms of slump flow diameter, T_{50} slump flow time, V-funnel time, and L-box height ratio. In addition to these test, the rheological properties of the carbon fiber reinforced self-compacting concretes were experimentally investigated. The results indicated that the workability properties of self-compacting concretes significantly affected by the carbon fiber addition. It was also observed that the use of carbon fiber increased the superplasticizer demand.

Keywords: Carbon fiber; Experimental study; Self-compacting concrete; Silica fume; Workability properties.

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ÖZET

KARBON LİF TAKVİYELİ KENDİLİĞİNDEN YERLEŞEN BETONLARIN İŞLENEBİLİRLİĞİ ÜZERİNE DENEYSEL BİR ÇALIŞMA

ASAAD, Ghazala Younus

Yüksek Lisans Tezi, İnşaat Mühendisliği Bölümü
Danışman: Doç. Dr. Erhan GÜNEYİSİ
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Bu çalışma karbon lif hacim oranının ve silis dumanının kendiliğinden yerleşen betonun taze özellikleri üzerine etkisini deneysel olarak incelemeyi hedefledi. Bunun için iki farklı kendiliğinden yerleşen beton grubu bu çalışmada üretildi. Birinci kendiliğinden yerleşen beton grubu silis dumansız üretilirken ikinci grup ise toplam bağlayıcı miktarının %10'u kadar silis dumanıyla üretildi. Her iki kendiliğinden yerleşen beton grubunda da toplam bağlayıcı miktarı ve su bağlayıcı oranı sırasıyla 530 kg/m^3 ve 0.37 olmak üzere sabit tutuldu. Ayrıca, toplam bağlayıcı miktarının ağırlıkça %30'u kadar uçucu kül kullanıldı. Bir de karbon lif miktarının ektisini incelemek için bu çalışmada %0, %0.5, %1.0 ve %1.5'lik 4 karbon lif hacim oranı seçildi. Toplamda 8 karbon lifle güçlendirilmiş kendiliğinden yerleşen beton karışımı tasarlandı. Kendiliğinden yerleşen beton karışımlarının taze özellikleri yayılma çapı, T_{50} slump akma süresi, V-hunisi akma zamanı ve L-kutusu yükseklik oranı açısından incelendi. Bu testlere ek olarak, karbon lif takviyeli kendiliğinden yerleşen betonların reoloji özellikleri deneysel olarak incelendi. Sonuçlar kendiliğinden yerleşen betonların işlenilebilirlik özelliklerinin karbon lif katılmasından önemli bir şekilde etkilendiğini gösterdi. Ayrıca, karbon lif kullanımın akışkanlaştırıcı ihtiyacını arttırdığı da gözlemlendi.

Anahtar kelimeler: Karbon lif; Reoloji; Kendiliğinden yerleşen beton; Silis dumanı; İşlenilebilirlik özellikleri.

To My beloved Parents,

My Brothers and Sisters

And all my family

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LIST OF SYMBOLS

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BS EN	British Standard
CEM	Customer Experience Management
CF	Carbon Fiber
CR	Crumb Rubber
CSA	Canadian Standards Association
CSA	Canadian Standards Association
CSA	Canadian Standards Association
CSA	Canadian Standards Association
CSF	Condensed Silica Fume
EFNARC	European Federation for Specialist Construction and Chemicals
EO	Ethylene Oxide
FA	Fly Ash
HPC	High-Performance Concrete
HVFA	High-Volume Fly Ash
ICAR	Concrete Systems Rheometer

LF	Limestone Filler
M	Marble Powder
MF	Melamine Sulfonate
NC	Normal Concrete
NF	Naphthalene Sulfonate
NVC	Normally Vibrated Concrete
PFA	Pozzolanic Material Fuel Ash
RPS	Redundant Power Supply
SCC	Self-Compacting Concrete
SCRC	Self-Compacting Rubberized Concretes
SF	Silica Fume
SP	Superplasticizer
USA	United States of America
VMA	Viscosity-Modifying Agent
VMA	Viscosity-Modifying Agent
VP	Volcanic Pumice Powder
VSI	Visual Stability Index
w/b	Water to Binder Ratio
w/c	Water to Cement Ratio

CHAPTER 1

INTRODUCTION

1.1 General

Vibration machines are used for vibrating the new casted concrete. This method and procedure is useful for removing the air bubbles inside the concrete mixes thus we can get a homogeneous concrete mix in this case we can say that this concrete is normal vibrated concrete (NVC) also compaction is a key for producing good concrete with optimum strength and durability (The concrete society and BRE, 2005). The concrete type which is expended in Japan in construction industry is special type of concrete and named (SCC) concrete. And is justice to say that Japan faced the problem of skills concrete workers shortages to product high quality durable concrete structures. To improve a new and different type of concrete that can finished and casted with a less number of expert workers Japanese Engineers and Researchers started their attempt and trials finally an idea of SCC first proposed in Japan in 1986 .So many studies are carried out by Ozawa and Maekawa to develop SCC at the university of Tokyo – Japan 1986 (Goodier, 2003).

Ozawa and Maekawa carried out many studies to develop SCC at the University from Tokyo in Japan**.** To pragmatically useful into SCC in civil engineering structures first country that worked intensively was japan (Okamura, 1997). Comparing with conventional concrete SCC has so many advantages, without vibration instruments SCC flows ubder its weight and it is suitable and ideal material for heavy reinforced concrete structures and soft finishing constructions and the first country whom they used SCC widely and practically was in civil engineering structures. The first country that worked intensively to pragmatically use SCC in civil engineering structures was japan (Okamura, 1997). SCC has many advantages through conventional concrete. SCC flows under own weight while does not require any vibrating instrument; it is an ideal material for soft finishing and for heavily reinforced structural members SCC is a new type of high performance concrete with superior deformability and segregation resistance. The mechanical durability and properties of SCC are greatly affected by its fresh properties, such as, flow ability filling ability, etc. (Okamura and, Ozawa, 1995; Khayat, 1999). Performance requirements for passing ability, segregation, and filling ability, the manufacturers must study he resistance of SCC very carefully and successfully. It means that this manufacture must be made and determined carefully and properly and using proper and sufficient methods of tests and also the three key fresh properties of SCC can be estimated by using variety methods. The three key fresh properties of SCC can be estimated by using different methods (Goodier, 2003; Ouchi et al., 2003; Takefumi and Yasunori, 2003). The great flowablity of SCC mixtures is investigate by using superplasticizer which influences a lot of fresh and hardened properties of SCC mixtures (Felekoğ and Sarıkahya, 2008; Sahmaran et al., 2006). Nippon Shokubai and Nippon Master Builder Technology invented the polycarboxylate founded superplasticizer (PC) in the mid of the 1980’s in Japan (Shi, 2009).

Development of self-compacting concrete has in japan (SCC) has been used for big office buildings and also for advanced kinds of extruded tunnels in combination with steel fibers (Persson, 1998; Persson, 1998). Use of SCC lowered the noise level on the diminished the action on the construction and environment location. SCC has been In Sweden, used for highway bridges so far and for slabs in a dwelling house where a 60% increase in productivity was observed (Persson, 1999). Use of SCC dropped the noise level on the diminished the action on the environment and construction location. SCC has been In Sweden, used for nineteen highway bridges so far and for slabs in a dwelling house where a 60% increase in productivity was observed (Persson, 1999). Use of SCC thus improved both the conditions for the work on the work site and surroundings beside problems with building moisture, a more modern technique for making is a number to be solved for concrete that is cast on site. Have been solved the Problems with building moisture by use of high-performance concrete (HPC; w/b < 0.38). Like normal compacting concrete (NC). An additive to increases the viscosity is often used when casting concrete under water and for SCC in tunnels (Persson, 1999). To increase the viscosity in SCC the following fillers may be used:

- Fly ash,
- Glass filler,
- Limestone powder,
- Silica fume (or silica fume slurry), and
- Quartzite filler (fine sand).

1.2 Benefits of self-compacting concrete

Fiber reinforced concrete significantly effect on the workability properties, which was depended on four reasons: (i) Fiber shape was more elongated that compared with aggregate; the surface area was large due to similar volume. (ii) Granular skeleton was expressively changed that caused from fiber stiff whereas fiber caused to fill the space between aggregate particular. Fiber length clearly compared due to stiff fiber push apart particles, which was caused to increase the voids of granular skeleton. (iii) The characteristic surface of concrete reinforced fiber was different from normal concrete. Finally, the anchorage was enhanced with utilizing fiber between of them and rounding matrix (Kochi and Nagaoka, 2000).

1.3 Research significance

At present very little information available in the use of silica fume and carbon fiber together in the self-compacting concrete. The main objectives of this research are the following : See the effect of carbon fiber content used in SCC. In addition to this, the influence of silica fume content was investigated. The fresh properties were examined in terms of slump flow diameter, slump flow time, V-funnel time, and L-box height ratio. The rheological characteristic of the SCC was also monifored within the scope of the study.

1.4 Outline of the thesis

Chapter 1 introduces the utilization of carbon fiber in the self-compacting concrete and research significant of the study.

Chapter 2 provides the literature review on the fresh properties, testing methods, principles, and fundamental materials.

Chapter 3 relates to the experimental study such as materials, mixture design, casting, proportioning, and test methods.

Chapter 4 presents the results and discussion of this study.

Chapter 5 summarizes the conclusions of the experimental study.

CHAPTER 2

LITERATUER REVIEW

2.1 Self-compacting concrete

The definition of self-compacting concrete (SCC) as described by the European concrete platform is expressed as follows: SCC is an inventive concrete that does not require vibration for compaction and placing. It is capable to flow under its own weight, completely filling formwork and investigation full compaction, even in the presence of engorged reinforcement (European Concrete Platform, 2012). Knowing this, it is implied that the industry can save many working hours by reducing the need for people vibrating the fresh concrete to compact it. When there is no need for compacting, the quality assurance of the vibrating as an uncertain factor, regarding the final result of the concrete, is ruled out. The most used argument for not using SCC is that it is more expensive than regular vibrated concrete. Despite the high expenses of SCC compared to regular concrete, it is probably more profitable in use by reducing the expenses of vibrating, and by quicker casting. In addition there are several other benefits with using SCC; with no need for vibrating, the working environment is better, the surfaces are improved, there is less need for rework, the execution is more rational, and we get more homogeneous concrete which gives better durability. The downside with SCC is that because of the rheology, the formwork needs to be tighter for the concrete not to flow out (Fsdahl, 2012).

Another way to save working hours is by adding fiber as a substitute to rebar. By mixing fiber in the fresh concrete increased tensile strength in the hardened concrete can be achieved without need for iron fixers prior to casting. Fiber in regular vibrated concrete is more uncertain, due to that when vibrating, the fiber will form a cylinder around the vibrator and may not be dispersed as required. A disadvantage by use of fiber is that the amount that can be used is very limited. The reason is that when using a large amount of fiber the flow properties of the concrete are reduced and in the worst case, fiber balling occurs, thus the fiber are not properly dispersed, resulting in irregular and unreliable concrete. Different manufacturers recommend different amounts of fiber. The recommended maximum amount varies from 1.3 vol-% to 3 vol-% of concrete (Fibercon, 2012; Ochi et al., 2007).

2.2 Properties of self-compacting concrete

At this stage, the properties of self-compacting are important for defining SCC and its categories Self-compacting categories exactly are related to the fresh properties. There are many variety definition of SCC, but the most common one:- Is when the concrete able to fill the formwork completely under the effective of its own, while occurring homogeneity even in the exist crowded reinforcement, and then consolidating without using vibrating compaction (The Concrete Society and BRE, 2005). There are three basic fresh properties for SCC: the filling ability, passing ability and resistance of segregation (Testing-SCC, 2005, the Concrete Society & BRE, 2005). The SCC features to move under its specific weight and the framework totally filled is known as filling ability. The SCC features to move through related obstacles for instance narrow space with no blocking possibility and reinforcement is Segregation resistance which is SCC feature to keep on homogenous after and through placing and transporting functionality. The ability of passing has differentiated SCC with the other consistence concrete with high characteristic. Furthermore, other characteristics of SCC able to keep on its own property when the quantity and the quality of condition’s environment and constituent materials are change (Domone, 2000).

2.2.1 Categories of self-compacting concrete

SCC can be categorized as three different types, Viscosity Modifying Agent (VMA), powder or integrated type, which based on the technique of offering viscosity (Dehn et al., 2000; Holschemacher and Klug, 2002; Nawa et al., 1998). Powder, which considered as a type of SCC basically, it can be characterized by powder content with high content and w/b ratio with low content, for limiting the free water contented and enhance the plastic viscosity which they are necessary. This type can be considered as a first generation of SCC types. The main success factor can be take it by maximize the content of powder and minimize the ratio of w/b and using superplasticiser to offer consistence.

Mixes are sensitive to changes in constituent materials because of the high powder content, powder-type SCC. For controlling strength and heat of hydration usually additions are used to replace cement. Such concretes are foreseeable to have a high shrinkage, and low permeability due to the low w/p ratio. Attention should be paid to the interactions of superplasticisers and powders (Liu, 2009). Viscosity-modifying VMA, which considered as a type of SCC and can be realized by high viscosity of VMA which modifying agent dosage, basically can be added to maximize the viscosity of plastic. As compared to powder's characteristics, VMA basically is higher in ratio of w/p or superplasticiser dosage to provide a satisfied ability of filling. Because of viscosity is controlled by the addition of VMA Powder content is less. Attention should be paid to the compatibility between superplasticisers and VMAs (Liu, 2009). To improve the robustness of powder type SCC by adding a small amount of VMA Combined-type SCC is developed. In with mixes, the contents of VMA mainly are less than compared with those in VMA of SCC. Furthermore, the ratio of W/b and powder content basically are less than compared with those in powder of SCC. The viscosity can be provided by powder with VMA. To have high filling ability, high segregation resistance and improved robustness this type of SCC was reported (Khayat and Guizani, 1997). Attention should be paid to the compatibility between superplasticisers, VMAs and powders. However, since there is no clear division among the above three types, SCC is more easily divided into two kinds, with or without VMA (Liu, 2009).

2.3 Fresh properties

Fresh Properties, basically SCC able to characterize as passing ability, robustness, filling ability and segregation resistance, and those mentioned characteristics have to persist through placing and transport (Liu, 2009). Accordingly, filling ability could reflect the SCC deformability, on the other hand the fresh concrete ability to change its own form under related weight (Khayat, 1999b; Okamura and Ozawa, 1995). The deformability consists of two different aspect: the capacity of deformation which have maximum capability to deform, that illustrate the distance how fast flowing of concrete, and the velocity of deformation which indicate the related time have to take for finishing the flowing of concrete, basically illustrate velocity how fast flowing of concrete; and deformation velocity refers to the time taken for the concrete to finish flowing, that is, how fast concrete can flow. And the balance between the capacity of the deformation and the the velocity of the deformation is filling ability for instance, the concrete with the capacity of the high deformation as well as the velocity of the very low deformation is going to be very viscous also it will take long time in order to fill framework (RILEM TC 174 SCC, 2000). However, passing the ability is considered unique to the SCC. Maily it determines how fine the mix is able to flow through the confined as well as the constricted spaces as well as the narrow openings, that mainly ensure the particular applications in the densely reinforced the structures like the bridge decks, the abutments, the tunnel or the segments of the tubing. Mainly depend on the blocking risk that results for interaction between the obstacles and the constituent materials (Liu, 2009). The resistance of the segregation is occasionally called as “stability”. Ever since the SCC is mainly composed of the materials of the diverse sizes as well as the exact gravities, generally it’s susceptible to the segrregation. The segregation is include in between solid and water or aggregate and paste or coarse and mortar. Generally, the aggregate in both of the stationary and the flowing states (RILEM TC 174 SCC, 2000). However, the three main properties that mentioned above are related to some of the extent and the interdependent. Generally, any change on of the properties will cause a change in one or the others. The ability of the poor filling as well as the segregation both of them can result in inadequate passing capability, for example, blocking. The risks of the segregation mainly increase as the ability of the filling increases. The SCC is in fact considered as a trade-off between the ability of the filling and the resistance of the segregation as described in Figure 2.1. Also, this considered as a very broad or comprehensive group of concretes with widespread range of properties, and it can be adjusted to outfit diverse applications. For instance, the ability of filling of the used SCC in the sloping ramps which was lower than the trench footings, in general, the required ability of passing the SCC with the transport as well as the methods of placing (The concretcete society and BRE, 2005). Mainly SCC fresh properties are influenced by difference in fineness as well as the moisture aggregation contents, the dissimilar batchers of the superplasticizer or the cement and the changes in the environmental conditions, like the temperature and the humidity and etc. The SCC is better to have a tolerance to such changes. The robustness is the capability of concrete to maintain the properties with such changes. Fewer changes in properties mean more robust SCC is sometimes the consistence retention is also known as ‘open time’ when SCC keep on its specific properties, which can be considered as essential element for placing and transportation, especially in sit concrete. The main techniques that required to fulfilling the satisfied SCC properties can be summarized and illustrated in the Figure 2.1 (Liu, 2009).

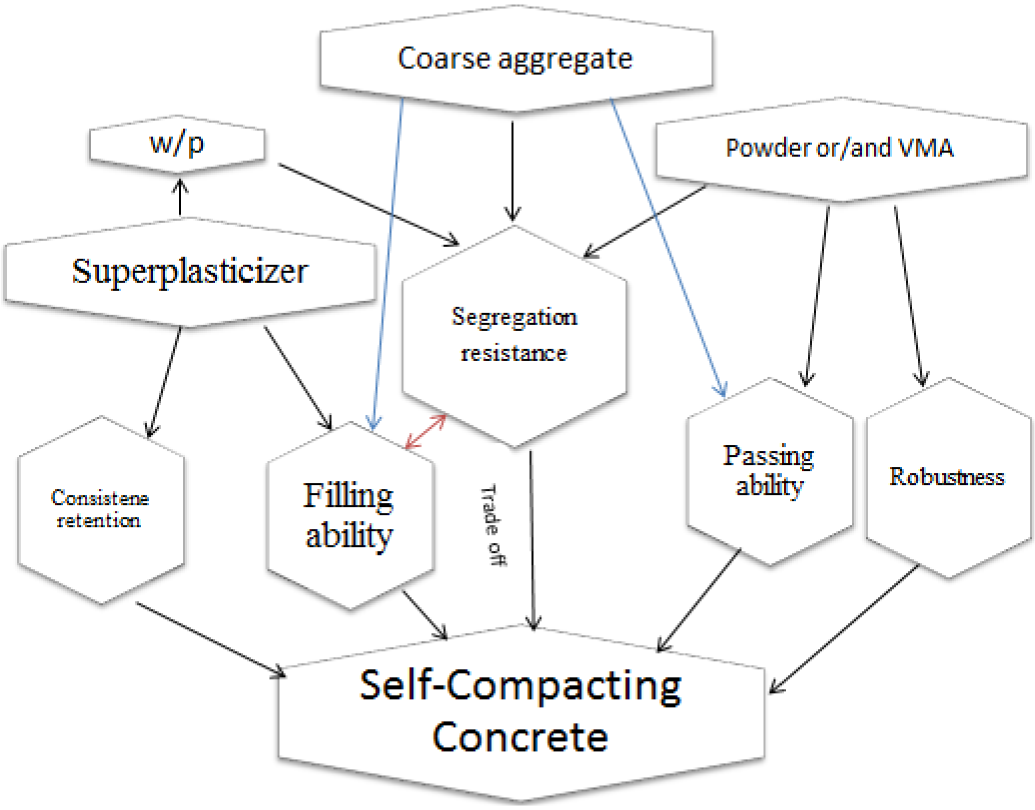


Figure 2.1 Schematic diagram of self-compacting concrete (Liu, 2009)

At this stage it is important defining SCC and its characteristics it is. Literally, self-compacting characteristics are related to the fresh properties. The definitions of SCC given in the literature vary most common definition is that a concrete that is able to flow under its own weight and completely fill the formwork, while maintaining homogeneity even in the presence of congested reinforcement, and then consolidating without the need of vibrating compaction (The Concrete Society and BRE, 2005). SCC has three essential fresh properties: filling ability, passing ability and segregation resistance (Testing-SCC, 2005; The Concrete Society and BRE, 2005).

2.4 Advantages of self-compacting concrete

The main comparison between self-Compaction Concrete (SCC) and Normal Vibration Concrete (NVC), SCC able to enhance the conditions of working and productivity, as well as enhanced the required qualities (Schutter et al., 2008; The Concrete Society and BRE, 2005). As a result of eliminating the compaction of internal segregation between surrounding liquid and solid particles are eliminated which comprises from less porosity of transmission zones among paste and aggregate, and more concrete's colour (RILEM TC 174 SCC, 2000). Enhanced SCC finish can be expected and strength, durability (Schutter et al., 2008; The Concrete Society and BRE, 2005).

Figure 2.2 shows a very good finish effect, in a steel mold, a pure cement SCC placed demoded 24h after casting. The surface is so dense and smooth that it can reflect light Regarding the construction of concrete, the main structure of performance could be improved with maximizing reinforcement capacity (volumes), the limitation of cracking by take advantage of smaller diameters of bar as well as utilizing complex framework. All the mentioned characteristics increase the compaction's difficulty (Okamura and Ouchi, 2003a; RILEM TC 174 SCC, 2000). Generally, SCC able to meets all the above structures by constructing concrete with casting homogeneous in possible congested structures, also have ability to enhance the better effectiveness and the better efficiency on Decreasing in the time of the construction and the cost of the labour. The SCC is also can develop the enviroment of the workplace by decreasing the noise pollution and eliminate the issues of health problems that are associated with utilization of the vibration equipments like the deafness and the "white fingers" (RILEM TC 174 SCC, 2000). So the SCC is called (the quiet revolution in the concrete construction) (The concrete society and BRE, 2005). Accordingly, the products industry of precast concrete became the largest user of the SCC in Europ (Skarendahl, 2003). The SCC is mainly required higher powder as well as admixture contents (primarily the superplasticiders) than the NVC as well as the cost of the material is considered high (The concrete society and BRE, 2005). Mainly in the most cases the increment of the cost ranged between (20% - 60%) compared to the similar grade of NVC (Nehdi et al., 2004; Ozawa, 2001). Anyhow, in the very large structures the increased cost of material by the use of the SCC was mainly outweighed by the time of the construction as well as save the cost of labour (Billberg, 1999). The benefit of the SCC were mainly presented in the composite sandwich system that involve the casting NVC as well as the SCC in the layers within the similar elements of structure (Okamura and Ouchi, 2003a, Ouchi, 2001;

Ozawa, 2001). Furthermore, the increase in the content of powder and the admixture can cause higher sensitivity for example, reduce the robustness robustness of SCC to the variation of material the NVC, therefore, the greater care with the quality control is considered necessary (walraven, 1998).

Figure 2.2 Excellent finish of a neat cement SCC (Liu, 2009)

For much concrete construction, the structural performance is improved by increasing reinforcement volumes, limiting cracking by minimizing the cost of labor and the time of construction. SCC able to enhance the environment of workplace by minimizing pollution of noise and avoiding the problems of health which associate with the use of equipment's vibration for instance meets the above developments by making casting homogeneous concrete in congested structures possible; it also improves efficiency and effectiveness on site by reducing the construction time and labor cost. SCC also improves the workplace environment by reducing noise pollution and eliminating the health problems related to the use of vibration equipment such as white fingers and deafness (RILEM TC 174 SCC, 2000). SCC is therefore called the quiet revolution in concrete construction (The Concrete Society and BRE, 2005).

2.5 Material used in self-compacting mixture

2.5.1 Fly ash

The product which is a by-product of electricity production in coal-fired power stations and called FA Pulverized fuel ash. Includes calcium, alumina, silica, iron and different minor components. Because of formation with higher temperature, basically those are considered in particles and glassy phase, especially those which are under 45 µm, can be considered as totally spherical. Mainly, fly ash is really presented. In the UK, approximately 250 million tons are stored, as well as approximately 5.5 million tons are manufactured annually. Furthermore, not completely fly ash are utilizable, accordingly 50% of yearly manufacturing are land filled. In the last years, specially in 2007, approximately 58% of manufactured FA, basically was utilized in the products of construction for instance grouting, mixed cement and raw material of cement, manufacture of aerated blocks, non-aerated blocks and concrete additions, fill and ground handling. The following realized benefits of utilizing FA, basically there are a better ability to maximize the using amount (Liu, 2009).

2.5.1.1 Fly ash in concrete

The fly ash in the concrete as presented below can be utilized in the concrete as: type I the addition complying to the BS EN 12620 (2002), or type II the addition complying to the BS EN 450 (2005) as the filler aggregate, the BS EN 450 is mainly include two types with the type S the fly ash is being finer as well as the contribution is became greater strength as shown in Table 2.1.

Table 2.1 Classification of FA according to BS EN 450-1 (2005) and BS EN 12620 (2002)

SPECIFICATION	FINENESS	APPLICATION
BS EN 450 (2005)	Category S: ≤ 12.0 % retained on the 45 µm sieve	Type II addition
	Category N: ≤ 40.0 % retained on the 45 µm sieve	
BS EN 12620 (2002)	70~100% passing the 63µm sieve	Type I addition

In addition as well as, it according to BSEN 13055-1(2002) also we can use light weight filler aggregate and given in Table 2.2 (ASTM C 618, 2003) another adopted classification and it is classified according to the total content of SIO_2, AI_2O_3, Fe_2O_3

and also according to the types of coal and it was done by ASTM compared with Class F and class C of FA has higher CaO, MgO and SO_3 FA is a pozzolanic material fuel ash (pfa, but now commonly called fly ash) at the same time Class C shows direct cementations activity. Also it can be seen that the utilization of class F of FA was approved in UK (Manz, 1999).

Table 2.2 Classification of FA according to ASTM C618 (2003)

CLASSIFICATION	TYPE OF COAL	$SIO_2 + AL_2O_3 + Fe_2O_3$ (%)
Class C of Fly ash	Ash Lignite or subbituminous Coal	≥ 50.0
Class F of Fly ash	Bituminous or anthracite Coal	≥ 70.0

the most broadly utilized additions in concrete is the (Fly Ash) that had been broadly investigated and researched over the past years also there are several puplications related to its numerous roles in the concrete follows summation is the physical and chemical effects on concrete performance.

2.5.1.2 Physical effects

The relative particle density of fly ash (typically 2.3 g/cm^3) is lower than that of cement 3.12 g/cm^3. The total volume of cementations materials will increase if cement is replaced by FA by weight, for example by about 10% at 30% replacement. Figure 2.3 showed 10% - 50% of FA that reduce the demand of water of the paste because of the increased significantly (Dietz and Ma, 2000).

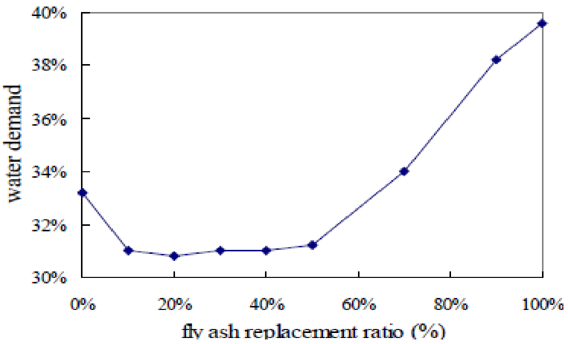


Figure 2.3 The influence of FA on water demand of concrete (Dietz and Ma, 2000)

2.5.1.3 Chemical effects

At the early ages fly ash shows very little pozzolanic reaction and, rather like filler, generally serves as nuclei for precipitation at early ages of concrete structures ,the rate of pozzolanic reaction comparing to that of the portland ordinary cement lead to lower strength and other properties and specifications comparing to 100% portland mixes (Liu, 2009). The participating of fly ash for strength is higher in concrete mixes with lower w/p ratio (BiJen and selst 1993; Poon et al 2000). For example at 28days age of mixes, the compressive strength with a rate of 45% of fly ash and w/p ratio is 30% lower than that of the control mixture with absence of fly ash. This reduction in spite of was 17% when the w/p ratio reduced to 0.30 (Lam et al., 1998). Extra lowering of w/p ratio to 0.19 did not give a sufficient strength of the concrete mixtures. So higher volume of fly ash but with decreasing the w/p ratio there is the possibility of high strength, this procedure is realized by using super plasticizers. Since the pozzolanic reaction consumes some lime, it has been cleared that using fly ash in concrete mixtures causing faster carbonation (Neville, 1996). The results that obtained does not reflect the true performance of fly ash of slow hydration because the results were based on the acceleration carbonation testing and causing lowering the long term permeability thus reducing the accessibility of CO_2 to the concrete (Sear, 2005) listed so many types of concrete with participating up to 50% of fly ash that has been that has been exposed for two years indoors and outdoors that actually fly ash reducing ingress of CO_2 and other researches and studies show that the duration of curing shows conditions and concrete strength had greater effects on carbonation than FA content (Matthews, 1995; Thomas and Mattews, 1994).

Temperature has a big effect on rate of the pozzolanic reaction, and so increasing temperature leads to improve strength of FA concrete. Other thing is favorable which is heat curring .separatelly from the glassy silica and alumina content the reactivity degre of fly ash is generally determined by the its own fineness (Helmuth, 1987). For example pozzolanic activity of SF is ordinary higher than that of fly ash but when finely grounded of FA can obtain the same activity to SF .the total content of SiO_2 and Al_2O_3 in this research was 91.4 in the SF and 85.73 in the FA. The other materials that have significant effects are calicium osides and smaller amounts of sodium and potassium osides and generally the low calcium fly ash (total CaO less that 10%) contains an alumina silicate. Type glass and no crystalline compounds of calcium and the high calcium fly ash (total CaO more that 15%) consists of a calcium alumina silicate glass and crystakkine compounds of calcium such as C_3A, C_4A_3S, CS and CaO due to the higher CaO content as presents in Table 2.3. Class C is so reactive that class F fly ash. It can from cementations products without the addition of calicium hydroxide (Manz, 1999).

Table 2.3 Classic range of chemical compositions of FA (Liu, 2009)

CONSTITUENT	RANGES	CONSTITUENT	RANGES
Aluminum (% by wet as Al_2O_3)	20~40	Silicon (% by wet as SiO_2)	38~52
Calciuim (% by wet as CaO)	1.8~10	Sodium (% by wet as Na_2O)	0.8~1.8
Chlorides (% by wet as Cl)	0.01~0.02	Sulphates (% by wet as SO_3)	0.35~2.5
Free calcium Oxide (% by wet)	<0.1~1.0	Titanium (% by wet as TiO_2)	0.9~1.1
Iron (% by wet as Fe_2O_3)	6~16	Water soluble sulphates (G/L as SO_4)	1.3~4.0
Magnesium (% by wet as MgO)	1.0~3.5	Loss on Ignition (%)	3~20
Potassium (% by wet as K_2O)	2.3~4.5	Ph	9~12

2.5.1.4 Fly ash in self-compacting concrete

Fly ash in self compacting concrete Because of hydration heat reduction and water reducing properties also the effect on the thixtropic performance ,fly ash was used in SCC .The physical and chemical effects of fly ash also have been seen in substantial researche conducted on SCC with participating up to 40% fly ash in recent years (Liu, 2009). Figure 2.4 shows that Using of 17-60% of fly ash in SCC to reduce super plasticezed usage to get the same slump test flow comparing with SCC made with portland cement .Such as SCC mixes showed better slump retention and segregation resistance .Sukumar et al .reported and publeshed that the relation between fly ash and super plasticezed dosage exists with SCC mixes with 8-52% FA the slump test of 742-793 mm and w/p of 0.31-0.34 .The super plasticezed dosage decreases parallel with an increase in fly ash content up to 39% and higher FA incorporation however did not change the superplasticizer required (Bouzoubaa and Lachemi, 2001; Sukumar et al., 2008).

Generally, with the help of with increasing of strength we can reduce of early crack in SCC low permeability ,low drying shrinkage of SCC and good freeze –thaw were obtained by incorporating 30% - 40% of FA.also FA has a similarity of affect to VMA on fresh concrete making better viscosity of fresh concrete and saving durability constant 28 days compresive strength of such SCC could reach 71 MPa (Xie et.al., 2002). Because of slower reactivity of FA and delaying effects of super plasticizer and VMA, SCC incorporating FA has a long setting time The setting time of SCC with %40-60 class F of FA in weight is 3-4 hours more than that of a control %100 cement NVC of the same 28 days compressive strength (Bouzoubaa and Lachemi, 2001), an additive (accelerator) was used to improve SCC to get early strength (Christensen and Ong, 2005) somethings considered such as chemical composition of which is unknown. A small quantity of Na_2SO_4 or K_2SO_4 together with $Ca(OH)_2$ or curing for a longer time were considered too for increasing early strength of HVFA SCC (Poon et al., 2003; Shi and Day, 2000). For extending the concept of HVFA concrete to SCC investigations on SCC incorporating higher proportions of FA in SCC is necessary in spite of there are a few researches were published in this subject and topic (Poon et al., 2003; Shi and Day, 2000).

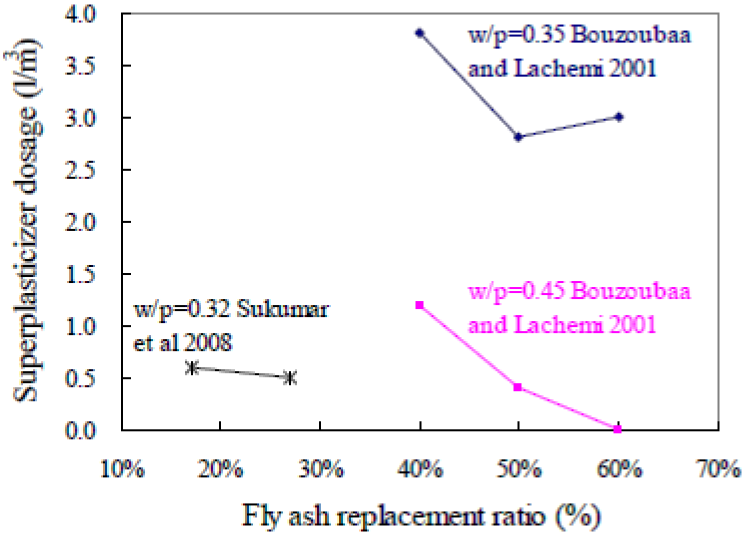


Figure 2.4 Effect of FA on superplasticiser potion of SCC (Bouzoubaa and Lachemi, 2001; Sukumar et al, 2008)

Güneyisi (2009) studied the usability of untreated crumb rubber as a partial substitute of fine aggregates with and without FA in the application of SCC was investigated experimentally. For this purpose, a water–cementations material ratio of 0.35, four designated crumb rubber contents (0, 5, 15, and 25% by fine aggregate volume), and four FA content 0, 20, 40, and 60% were considered as experimental parameters. Test results indicated that use of crumb rubber CR without FA aggravated the fresh properties of self-compacting rubberized concretes (SCRC) (slump flow diameter, T_{50} slump flow time, V-funnel flow time, L-box height ratio, initial and final setting times, and viscosity). However, the use of CR with FA amended the fresh properties of SCRC.

2.5.1.5 Advantages of fly ash and silica fume in concrete

From a review of literature, the advantages of the effects of FA on concrete, and the small size and spherical form of FA particles influence the rheological properties of cement paste, causing a reduction in the amount of water required for a given workability when FA is used as a partial replacement for cement. The reduction of water depends on the mixture proportions of the fresh concrete, the shape and fineness of FA particles and the shape factor of the aggregates (Lane and Best, 1982; Berry and Malhotra, 1986). The hydration of FA-cement concrete is usually accompanied by a reduced amount of heat, which has been particularly favored in mass concrete application. It is also realized that most pozzolan-cement concrete results in a slower gain of strength at early age while the ultimate strength is comparable or even higher than that of a concrete without fly ash (Lane and Best, 1982; Berry and Malhotra, 1986).

FA decreases creep and drying shrinkage (Ghosh, 1994). The pozzolanic reaction of FA concrete produces denser gel products, reduces permeability of concrete and thus improves the resistance to chemical attack, namely, sulphate attack and alkali-aggregate reaction (Berry et al., 1987; Nasser et al., 1990). SF, because of its high reactivity potential due to its large surface area 20 to 23 m^2/g, it has attained prominence in recent years. Condensed SF not only acts as an efficient pozzolan by reacting with the lime liberated during the hydration of Portland cement, but also influences the rate of hydration (Malhotra et al., 1987).

There are a number of applications in which condensed SF can be incorporated to advantage in concrete. They may be enumerated as follows (Ghosh, 1994). Studies indicate that the use of up to 12% condensed silica fume is advantageous for increasing strength levels and at the same time using less cement (Skrastins et al, 1983). However, the Canadian Standards Association (CSA) recommends the use of 10% of binder as SF only in order to limit drying shrinkage and high water demand of concrete (Skrastins et al, 1983). SF increases the early age strength of concrete. Its use, thus, offsets the drawback of fly ash in concrete, namely low early age strength development (Mehta and Gjorv, 1982). Use of SF reduces permeability of concrete thereby enhancing its resistance to chloride attack. Best performance in this respect has been seen in concrete containing 10% SF (Marusin, 1986). Judicious use of SF, provides high strength concrete. In ordinary concrete, the strength, primarily a function of the cementitious binder system, is usually low when compared with the strength of coarse aggregate. To obtain 100 MPa (14500 psi) strengths or higher, it is necessary to have a high-strength cement binder system together with relatively strong aggregates. This can be achieved by using a combination of condensed silica fume, Portland cement, and superplasticizers (Bache, 1981). Concrete containing SF performs satisfactorily under repeated cycles of freezing and thawing. Investigations by Carette and Malhotra (1983) and Malhotra (1984) revealed that SF concrete with air-entrainment performed satisfactorily under freezing and thawing cycles as per ASTM C666 tests. Limited published data (Aitcin et al., 1980), indicate that condensed SF in concrete, like other pozzolans is equally effective in controlling alkaliaggregate expansion in concrete. No published data are available on creep of concrete incorporating 5 to 15 % of condensed SF. However, tests by Wolsiefer (1984) on 90 % CSF concrete yielded very low creep values (Wolsiefer, 1984).

Güneyisi et al. (2012) studied for this purpose, an experimental program has been conducted to investigate the possibility of using marble powder (M) and limestone filler (LF) in the production of SCCs with and without FA. Two series of concrete mixtures containing binary and ternary blends of fine materials were designed and cast with a constant water–binder (w/b) ratio of 0.35. Test results showed that high replacement level of the filler slightly affected the fresh properties of the SCCs adversely. However, the inclusion of fly ash mitigated such problems. Moreover, mechanical and transport properties were improved by using marble powder and limestone.

2.5.2 Fiber types

Steel and plastic fiber is the most common fiber types applied by the building industry; other fiber types like glass and carbon fiber contribute a smaller share to the market (grünewa, 2012). Fiber affects the characteristics of concrete in the fresh state. They are needlelike particles that increase the resistance to flow and contribute to the formation of an internal structure of aggregate grains and fiber (Holschemacher and Dehn, 2002).

The mechanical interaction of fiber and aggregates dominates the flow behavior; the surface area of these fiber types is comparable to coarser sand fractions. In contrast, thin plastic fiber and fiber at a very high aspect ratio can have a much higher surface area. Plastic fiber mainly affects the rheological behavior of the paste. Due to their flexibility, the mechanical interaction with aggregates is much less pronounced but they can still form a network with aggregates and other fiber. The flexibility of fiber has two effects: the deformation of fiber and the formation of entangled structures (Yamanoi et al., 2010). The shear viscosity increased at increasing flexibility (Keshtar et al., 2009). The presence of steel fibres affects the yield stress of concrete but alters the paste characteristics to a minor degree. A structure produced with a fiber-reinforced concrete still can have a smooth and faultless surface, even at a relatively small slump flow of 550–600 mm or medium slump of 100–150 mm (Grünewa, 2012).

2.5.2.1 Carbon fiber

The new type of high strength materials is carbon fiber (CF). CF has been defined as fiber that contained of 90% carbon, which gained from appropriate fiber pyrolysis under controlling. CF was getting in 1879. Furthermore, CF was utilized in electric lamps when Edison approved this application. Though, the production of commercial was started and caused to patent in early 1960s, as the requests of the atmosphere manufactory-especially for lightweight materials became and military aircraft-for better of paramount importance. Additionally, CF has the application of found wide in civilian aircraft and commercial, manufacturing, recreational, and transportation for shops. Other application of CF useful is utilized as composites materials with a lightweight matrix, also CF composites are preferably possible to lower weight, stiffness, strength, and outstanding applications are weakness characteristics are critical requirements, although; it was used in many submissions. Moreover, the providers of Advanced Composites Materials Association released 1997 manufactory numbers on worldwide consignments of CF for composites. Presently, there a few countries that can be produced a large quantity of CF such as American United States of nearly 60% and 50% production capacity of CF patent from Japan, on the other hand, the large amount of Pith based CF produced in Japan (Shehata, 2001).

Commercially there are two types of carbon fibers available in the markets and they can be used in concrete .first is Polyacrylonitrille (PAN) based and the second is pitch –based carbon fibers .the first one which is PAN-based carbon fibers have a very high modulus of elasticity and high tensile strength and they have been widely and mostly using in producing aerospace and sport equipements (Ali et al., 1972). Rarely PAN-based fibers are using in civil engineering applications and projects now and presently because of the high cost but we must not forget PAN-based were the first type of discrete short carbon fibers used in reinforced concrete In spite of PAN-based fibers (Ali et al., 1972).

Inversely to the first one, Pitch-based carbon fibers useually and widely used in civil engineering projects and applications because of the suitable low proces and cost and also it has a lower modulus of elasticity comparing with PAN-based fibers .Also Pitch–based fibers due to the light weight ,good chemical stability and high heat of the excellent arasion resistance. It can be used in most of industrial fields than PAN-based fiber. Pitch-based CF is used in many industrial fields due to their, high heat, good chemical stability, lightweight and excellent abrasion resistance (Safiuddin, 2010). Pitch-based carbon will lead to increase in flexutal strength about 85%, flexural toughness about 205% and compressive strength about 22% if it was used in reinforced concrete, in the other hand electrical resistivity can be dcreased up to 83% and drying shrinkage up to 90% (DDL and Chen, 1993; DDL, 1992).

Table 2.4 Fiber type and material characteristics (Holschemacher and Dehn, 2002)

Fibre type	Typical fibre Diameter (µm)	Typical fibre length (mm)	Density (g/cm^3)	E-modulus (kN/mm^2)	Tensile Strength (N/mm2)	Elongation at break (%)
Steel fiber- hooked end	500–1300	30–60	7.85	160–210	>1000	3–4
Crimped	400	26–32	7.85	210	980	
AR-glass fibre Polypropylene Fibre	3–30	3–25	2.68–2.70	72–75	1500–1700	1.5–2.4
monofilament	18–22	6–18	0.91	4–18	320–560	8–20
Fibrillated	50–100	6–19	0.91	3.5–10	320–400	5–15
Polyacrylnitrile Fibre	18–104	4–24	1.18	15–20	330–530	6–20
Carbon fibre	5–10	6	1.6–2.0	150–450	2600–6300	0.4–1.6

Yakhlaf et al., (2013) studied for describing the effects of discrete pitch carbon fibers on fresh properties of SCC, this example can be occurred. Producing different CF reinforced self-consolidating concrete mixtures incorporating and participating of 0%, 0.25%, 0.5%, 0.75% and 1% CFs by concrete volume with two water–to–binder ratios (0.35 and 0.40). The abilities mentioned before (filling and passing) of concrete mixtures was determined with respect to slump flow, J-ring slump flow and T50 slump flow time. By sieve stability test we can evaluate and control the segregation resistance of the concrete mixtures. Visual stability index (VSI) also used to know access the segregation resistance of mixtures also the new and fresh concrete mixtures are tested to know the air content and unit weight and for observing the distribution of fibers, the hardened concrete was tested by scanning Electron Microscope (SEM). The results are show that the increasing amount of carbon fibers leads to decrease the filling and passing ability of concrete. In spite of the CFs have no adverse effects on the segregation resistance of concrete. Also no significant air entrapment occurred in the presence of carbon fibers. CFs was good distributed and they weakly decreased the unit weight of concrete.

2.5.3 Silica fume

Silica fume (SF) is a by-product which results from the manufacturing of silicon metal or ferrosilicon alloy. It is collected from the gas exhausted from electric arc furnaces as a result of burning high-purity quartz, coal and wood chips. The collected material contains amorphous silica, the amount of which depends upon the alloy type. For metal containing 98% silicon, the SiC > 2 content in the collected silica fume is in the range from 87% to 98%. For ferrosilicon alloys containing 50% and 75% silicon, the SiC > 2 content in the SF is between 61% to 84% and 84% to 91%, respectively (ACI234R-3, 1999).

The silica fume particles are spherical with a very high surface area (20,000 m^2/kg measured by nitrogen-adsorption method). The average particle diameter is about 0.1 pm which is 100 times finer than an average Portland cement particle (ACI 234R-3, 1999). Oversize particles (larger than 45 pm) are generally composed of non-silica components. Due to its high glass content and fineness, SF exhibits a high pozzolanic reactivity. The high fineness of the SF makes it difficult to handle; for that reason different forms of SF are produced to overcome the difficulty encountered in its transporting and handling (ACI 234 R-3, 1999).

The ACI 234 R-3 (1999) divides the SF commercially available in the United States into four categories; as-produced SF: This category represents the SF as collected from the gas escaping from the furnace. Such a material has a bulk density of 130 to 430 kg/m^3 and is very difficult to handle. For that reason, the as-produced SF has not been used extensively in concrete production. (ACI 234 R-3, 1999). Slurred SF: This form of SF is water-based slurry that contains 42% - 60% silica fume by mass. This form is also available with added chemical admixtures (e.g. water reducer, high-range water reducer, retarders). The slurry is easier to handle compared to the as-produced SF. The bulk density of the slurry is in the range of 1320 to 1440 kg/m^3 (ACI 234 R-3, 1999).

Densified SF: This form of SF is produced by densifying the as produced SF; this process results in a material that can be handled as Portland cement or FA. The densification process is achieved either by compressed air or by mechanical densification. In the air-densification process, the as-produced particles are exposed to compressed air blown from the bottom of the silo where the particles are placed. The particles tumble forming agglomerates, which fall down and are collected periodically from the bottom of the silo. Because of the agglomerates are composed of particles that are weakly held to each other, such a material is expected to disperse easily in concrete during mixing. In the mechanical densification, the particles are mechanically compressed to form larger particles (ACI 234 R-3, 1999). Densified of SF is available with or without chemical admixtures (in the form of powder). The bulk density of the densified SF is in the range from 480 to 640 kg/m. When the density exceeds about 720 kg/m, the material may become difficult to disperse within the concrete matrix during mixing (Medhat, 2001).

As-produced SF: This category represents the SF as collected from the gas escaping from the furnace. Such a material has a bulk density of 130 to 430 kg/m^3 and is very difficult to handle. For that reason, the as-produced silica fume has not been used extensively in concrete production (Medhat, 2001). Slurred SF: This form of silica fume is water-based slurry that contains 42% - 60% SF by mass. This form is also available with added chemical admixtures (e.g. water reducer, high-range water reducer, retarders). The slurry is easier to handle compared to the as-produced silica fume. The bulk density of the slurry is in the range of 1320 to 1440 kg/m^3 (Medhat, 2001). Densified SF: This form of SF is produced by densifying the as produced silica fume; this process results in a material that can be handled as Portland cement or fly ash. The densification process is achieved either by compressed air or by mechanical densification. In the air-densification process, the as-produced particles are exposed to compressed air blown from the bottom of the silo where the particles are placed. The particles tumble forming agglomerates, which fall down and are collected periodically from the bottom of the silo. Because the agglomerates are composed of particles that are weakly held to each other, such a material is expected to disperse easily in concrete during mixing In the mechanical densification, the particles are mechanically compressed to form larger particles. Densified silica fume is available with or without chemical admixtures (in the form of powder). The bulk density of the densified SF is in the range from 480 to 640 kg/m^3. When the density exceeds about 720 kg/m , the material may become difficult to disperse within the concrete matrix during mixing (Medhat, 2001). Pelletized SF: Pelletized silica fume is produced by adding a small amount of water to the as-produced SF on a disk pellitizer. The agglomerated particles produced cannot be dispersed within the concrete during mixing; and for that reason, pelletized SF should not be used as concrete admixture. It can, however, be underground with the portland cement clinker to produce a blended cement (Medhat, 2001).

There are a number of applications in which condensed SF can be incorporated to advantage in concrete. They may be enumerated as follows; Studies indicate that the use of up to 12% condensed silica fume is advantageous for increasing strength levels and at the same time using less cement (Skrastins et al., 1983). However, the Canadian Standards Association (CSA) recommends the use of 10% of binder as silica fume only in order to limit drying shrinkage and high water demand of concrete (Skrastins et al., 1983). SF increases the early age strength of concrete. Its use, thus, offsets the drawback of FA in concrete, namely low early age strength development (Mehta and Gjorv, 1982). Use of SF reduces permeability of concrete thereby enhancing its resistance to chloride attack. Best performance in this respect has been seen in concrete containing 10% silica fume (Marusin, 1986). Judicious use of SF provides high strength concrete. In ordinary concrete, the strength, primarily a function of the cementations binder system, is usually low when compared with the strength of coarse aggregate. To obtain 100 MPa strengths or higher, it is necessary to have a high-strength cement binder system together with relatively strong aggregates. This can be achieved by using a combination of condensed SF, Portland cement, and superplasticizers (Bache, 1981). Concrete containing SF performs satisfactorily under repeated cycles of freezing and thawing. Investigations by Carette and Malhotra (1983) and Malhotra (1984) revealed that silica fume concrete with air-entrainment performed satisfactorily under freezing and thawing. Limited published data indicate that condensed silica fume in concrete, like other pozzolans, is equally effective in controlling alkali aggregate expansion in concrete (Aitcin et al., 1980).

2.5.4 Properties of silica fume

2.5.4.1 Physical properties

SF particles are extremely small, with more than 95% of the particles finer than 1 lm. SiO2 content of SF produced from different alloy sources (ACI 234R, 1995) as seen in Table 2.5. The typical physical properties are given in Table 2.6. SF colour is either premium white or grey as seen in Figure 2.5. Moreover, in Figure 2.6, the flow chart of SF production is given.

2.5.4.2 Chemical composition

SF is composed primarily of pure silica in non-crystalline form. X-ray diffraction analysis of different silica fumes reveals that material is essentially vitreous silica, mainly of cristobalite form. SF has a very high content of amorphous silicon dioxide and consists of very fine spherical particles. SF generally contains more than 90% SiO_2. Small amounts of iron, magnesium, and alkali oxides are also found. Oxides analyses of SF as reported by some authors are given in Table 2.7 (Siddique and Khan, 2011).

Figure 2.5 Silica fume (Siddique and Khan, 2011)

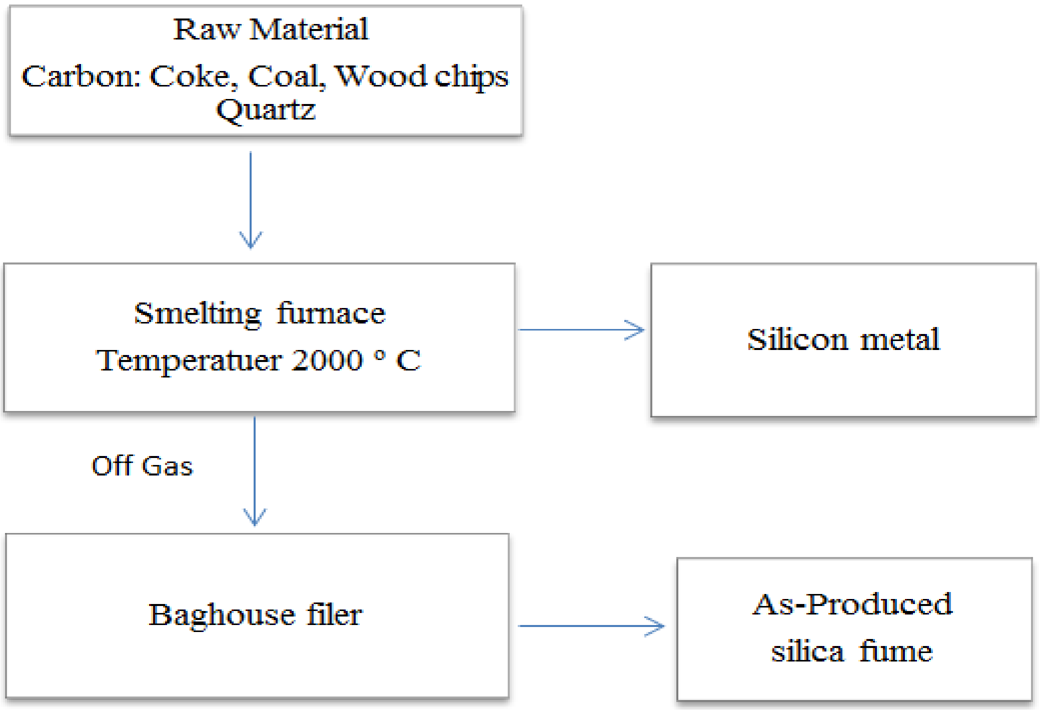


Figure 2.6 Schematic diagram of SF production (Siddique and Khan, 2011)

Table 2.5 SiO2 content of SF produced from different alloy sources (ACI 234R, 1995)

Alloy type	SiO_2 Content SF (%)
50% ferrosilicon	61-84
75% ferrosilicon	84-91
silicon metal	87-98

Table 2.6 Typical physical properties of SF VA 20180, USA (2005)

Property	Value
Partical size (typical)	< 1 m
Bulk density	
As- produced	130-430 kg/m^3
Slurry	1,320-1,440 kg/m^3
Densified	480-720 kg/m^3
Specified gravity	2.22
Surface area (BET)	13,000-30,000m^2/kg

Table 2.7 Chemical composition of SF samples (Siddique and Khan, 2011)

Oxides	Sandvik and Gjørv (1992)	Hooton and Titheringoton (2004)	Yazici (2008)
SiO_2	92.1	96.65	92.26
Al_2O_3	0.5	0.23	0.89
Fe_2O_3	1.4	0.07	1.97
CaO	5.5	0.31	0.49
MgO	0.3	0.04	0.96
K_2O	0.7	0.56	1.31
Na_2O	0.3	0.15	0.42
SO_3		0.17	0.33
LOI	2.8	2.27	

2.5.5 Advantages of using silica fume

As a producer, I would like to learn more about adding SF to my mix. What are its effects and where can I get more information. SF significantly improves the properties of fresh and hardened concrete. High tensile, flexural strength, and modulus of elasticity, This is some of the Advantages SF:

- Very low permeability to chloride and water intrusion,
- Enhanced durability,

- Increased toughness,
- Increased abrasion resistance on decks, floors, overlays and marine structures,
- Superior resistance to chemical attack from chlorides, acids, nitrates and sulfates and life-cycle cost efficiencies,
- Higher bond strength, and
- High electrical resistivity and low permeability (Siddique and Khan, 2011).

Güneyisi et al. (2013) studied the current study presents an experimental study conducted on the effectiveness of volcanic pumice powder (VP) on the fresh properties of SCCs with and without SF. 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 characteristics of the concretes were slump flow diameter, T_{500} mm slump flow time, V-funnel flow time, and L-box height ratio. The results have revealed that increasing the replacement level of VP generally resulted in the increase of fluidity of SCCs without loss of uniformity and with no segregation. Moreover, incorporation of SF provided significant increase in compressive strength while VP caused a systematic decrease.

2.5.6 Superplasticizer

Cement particles always flocculate and agglomerate when cement mixes with water, Electrostatic attractive forces and Van der walls forces will generate by electric charge on the surface of particles, this in large amount of free water will trap in the floor this leads to reduce the consistence of concrete mixture Superplasticizers and water reducing agents attach the cement particles causing a negative surface charge in this way imparting electrostatic repulsion and jetting which as a result will break the flocculation and agglomeration and liberate the trapped water as shown in Figure 2.7 (Uchikawa et al., 1997), as superplasticizers generate greater electrostatic and steric repulsive forces comparing with water reducing agents, and they get and obtain a result with greater consistence performance and longer consistence retention (Bonen and Shah, 2005; Uchikawa et al., 1995).

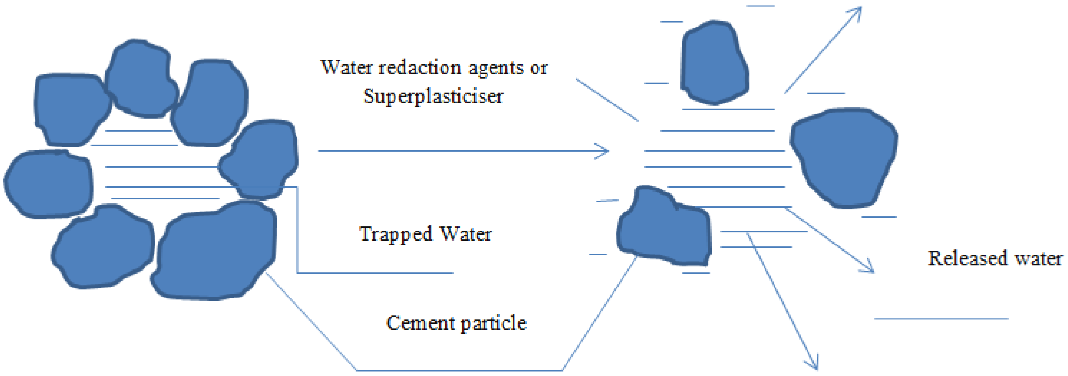


Figure 2.7 The effect of water reducing agents or superplasticizers on the flocculation of cement particles (Uchikawa et al., 1997)

2.5.6.1 Superplasticizer types

Superplasticizer types Sari et al. (1999) reported a nano metric, amorphous, silica fume can act as superplasticizer. However, the most commonly used are inorganic superplasticizers. Inorganic superplasticizers used in SCC can be divided into two types according to their dispersion mechanism: those based on electrostatic repulsion and those based on steric repulsion. Those mainly based on electrostatic repulsive forces include naphthalene sulfonate (NF), melamine sulfonate (MF) and amino sulfonate based agents. All of them contain a sulfonic group in the molecule which imparts a negative charge on the cement particles, thus causing dispersion (Kim et al., 2000; Nawa et al., 1998). Superplasticizers mainly based on steric repulsive forces include polycarboxylate based agents. They have a molecular structure composed of a backbone of a long straight chain of carbon atoms with side ethylene oxide (EO) chains which absorb water and produce a thick layer on the cement surface, thus generating effective steric repulsion (Yamada et al., 2000). In addition, the carboxyl group in the molecule also gives a negative charge to cement particles, thus providing some electrostatic particle repulsion. However, this is weaker than that of the sulfonic group (Uchikawa et al., 1995). The newly developed polycarboxylic acid-based superplasticizer is able to provide high consistence, proper viscosity and long consistence retention even in a small amount and at low w/c ratio. It is therefore especially suitable for SCC and is the most commonly used.

CHAPTER 3

EXPERIMENTAL STUDY

3.1 Materials

3.1.1 Cement

Ordinary Portland cement (CEM I 42.5R) coincided to ASTM type I grade and having a specific gravity of 3.15 g/cm^3 and specific surface area of 326 m^2/kg. Table 3.1 shows the chemical compositions and physical properties of Portland cement (PC), fly ash (FA), and silica fume (SF).

Table 3.1 Chemical composition and physical properties of PC, FA and SF

Preoperties	PC	FA	SF
CaO	62.58	4.24	0.45
SiO_2	20.25	56.20	90.36
Al_2O_3	5.31	20.17	0.71
Fe_2O_3	4.04	6.69	1.31
MgO	2.82	1.92	-
SO_3	2.73	0.49	0.41
K_2O	0.92	1.89	0.45
Na_2O	0.22	0.58	1.52
Loss on ignition	3.02	1.78	3.11
Specific gravity	3.15	2.25	2.20
Specific surface area (m^2/kg)	326	379	21080

3.1.2 Silica fume

Silica fume (SF) obtained from Norway was used. From the information provided by the supplier it had a specific gravity of 2.2 g/cm^3 and Blaine fineness of 21080 m^2/kg Figure 3.1. The chemical compositions and physical properties of Portland cement, fly ash, and silica fume are presented in Table 3.1.

Figure 3.1 Photographic view of silica fume

3.1.3 Fly ash

Class F fly ash (FA) according to ASTM C 618 (2000) with a specific gravity of 2.25 g/cm^3 and Blaine fineness of 739 m^2/kg that was utilized in the manufacturing of the SCCs. Figure 3.2 presents the photographic view of FA. The chemical compositions and physical properties of Portland cement, fly ash, and silica fume are presented in Table 3.1.

Figure 3.2 Photographic view of Fly Ash

3.1.4 Carbon fiber

CF used in this study that had the unit weight of 1.81 g/cm^3 and carbon percentage was 95. The length and diameter of fibers were 12 mm and 7.2 µm, respectively. The elastic modulus and tensile strength of CF were 228 GPa and 3800 MPa, respectively. Figure 3.3 shows the photographic view of CF.

Figure 3.3 Photographical view of carbon fiber

3.1.5 Superplasticizer

A polycarboxylic ether type of superplasticizer (SP), which acts by steric hindrance effect (Collepardi, 2005) with specific gravity of 1.07 was employed to achieve the desired workability in all concrete mixtures.

3.1.6 Aggregates

River gravel with a greatest size of 16 mm was used as a coarse aggregate while the mixture of natural and crush sand with a maximum size of 4 mm was used as a fine aggregate. Natural sand, crushed sand, and river gravel had the specific gravity of 2.66, 2.45, and 2.72 and the fineness modulus of 2.79, 2.38, and 5.68, respectively. Physical properties and sieve analysis results of natural aggregates are presented in Table 3.2.

3.2 Mixture design

Two mixtures of self-compacting reinforce and non-reinforce concrete mixture designed according to CF with total binder content of 530 kg/m^3 and w/b ratio of 0.37. Portland cement was substituted with the silica fume by weight at replacement levels of 0 and 10% in first and second self-compacting concrete series respectively. CF was incorporated to SCC by total concrete volume at fractions of 0, 0.5, 1.0, and 1.5% in first and second. Totally, 8 self-compacting concrete mixtures were produced according to above variables. The detailed mix proportions for self-compacting concrete are presented in Table 3.3. In mix ID, silica fume is represented by SF while carbon fiber is denoted by CF. For example; SF10CF5 indicates that the SCC is designed with silica fume content of 10% and CF volume fraction of 0.5%.

Table 3.2 Sieve analysis and physical properties of river sand, crushed sand and natural gravel

Sieve size	Fine aggregate (%)		Natural gravel (%)
	River sand	Crushed sand	
16	100	100	100
8	99.7	100	31.5
4	94.5	99.2	0.4
2	58.7	62.9	0
1	38.2	43.7	0
0.5	24.9	33.9	0
0.25	5.4	22.6	0
Fineness modulus	2.79	2.38	5.68
Specific gravity	2.66	2.45	2.72

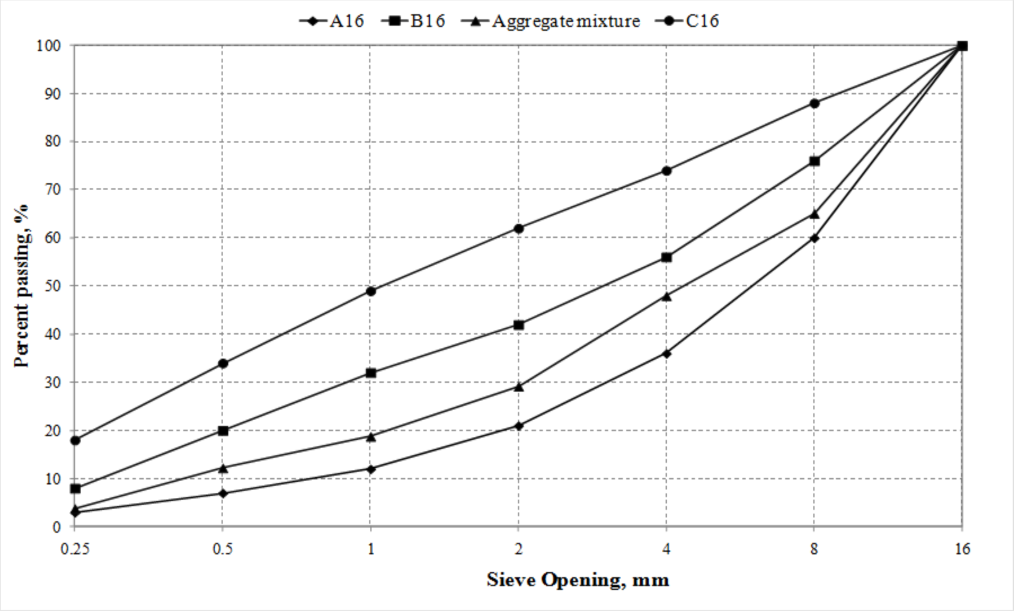


Figure 3.4 Sieve analysis of the mixture

Table 3.3 Mix proportions for carbon fiber reinforced SCC mixtures (kg/m^3)

	w/b	Binder				Water	Natural sand		Natural gravel	SP*
		Cement	FA*	SF*	CF*		River sand	Crushed sand		
SF0CF0	0.37	371	159	0	0	196.1	642.7	160.7	803.4	3.30
SF0CF5	0.37	371	159	0	9.05	196.1	639.1	159.8	798.9	6.89
SF0CF10	0.37	371	159	0	18.10	196.1	636.5	159.1	795.6	9.54
SF0CF15	0.37	371	159	0	27.15	196.1	633.9	158.5	792.3	12.19
SF10CF0	0.37	318	159	53	0	196.1	633.7	158.4	792.1	5.17
SF10CF5	0.37	318	159	53	9.05	196.1	631.6	157.9	789.4	7.33
SF10CF10	0.37	318	159	53	18.10	196.1	629.0	157.2	786.2	9.94
SF10CF15	0.37	318	159	53	27.15	196.1	626.4	156.6	782.9	12.56

*FA: Fly ash; SF: Silica fume; SP: Superplasticizer; CF: Carbon fiber

3.3 Concrete mix proportion

To achieve the same homogeneity and uniformity in all mixtures, a special batching and mixing procedure was followed since mixing sequence and duration are very vital in SCC production. Regarding to this procedure, the fine and coarse aggregates were poured in a power-driven revolving pan mixer and allowed to mix homogeneously for one minute. After that about quarter of the mixing water was added into the mixer and it was allowed to proceed the mixing for one more min. The aggregates, then, were left to absorb the water for 1 min. Afterwards, the powder materials (cement and fly ash and/or silica fume) were added to the wetted aggregate mixture for mixing extra 2 min. For the mixtures without fiber, the remainder of the mixing water including SP was added into the mixer. After SP with remaining water was poured into the mixer, the SCC without fiber was mixed for 3 min. and then left to rest for 2 min. Finally, the concrete was mixed for additional 2 min. to complete the production. The same sequence was followed for the composite mixtures with fibers, except that the fibers were added before adding the rest of mixing water with SP. Besides, the composite mixtures containing fiber were mixed for 5 min. and then left to rest for 2 min. The composite mixtures without fiber were mixed for a total time of 9 min. while those including fiber were mixed for a total time of 11 min. excluding the resting time. Finally, the fresh tests were applied on the SCC mixture.

3.4 Test procedure

The slump flow diameter, T_{50} slump flow time, V-funnel flow time, L-box height ratio, and L-box T_{20} and T_{40} flow time tests, of which test apparatus sketching was given in Figure 3.5, 3.6 and 3.7 were conducted with regard to recommendations given in EFNARC (2005) committee (European Federation for Specialist Construction Chemicals and Concrete Systems). Slump flow value, which is the primary check for the fresh concrete consistence to meet the specification, is a sensitive test. It is used for the description of the flowability of a fresh concrete in unconfined conditions. For this reason, it can normally be specified for all self-compacting concretes. T50 time that is the measured time for flowing of concrete to a diameter of 500 mm EFNARC (2005) provides additional information about segregation resistance and uniformity of concrete, which can be achieved from the visual observations during the test and/or measurement of T50 time. The typical slump flow in the range of applications is classified in three classes by EFNARC. The upper and lower limits for these classes are given in Table 3.4.

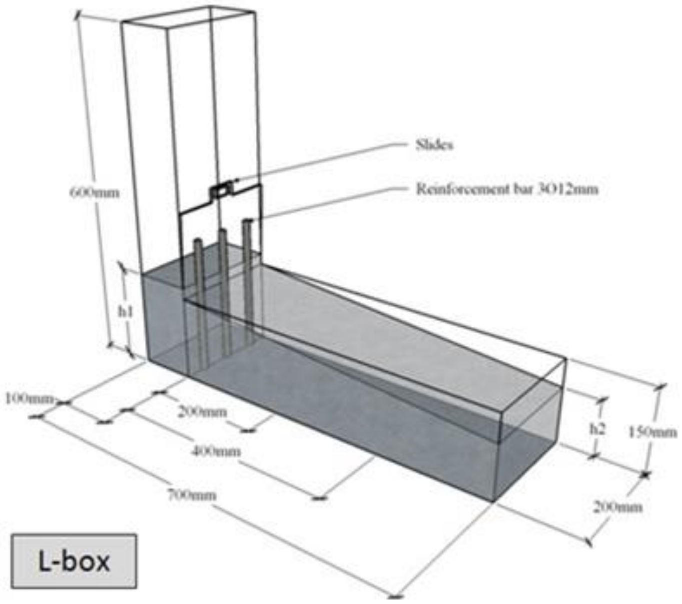


Figure 3.5 Sketch apparatus of L-box test

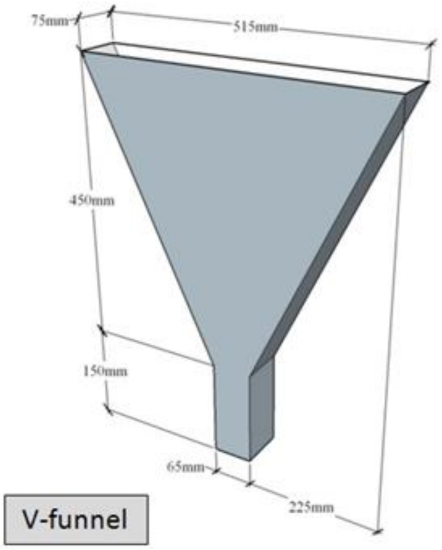


Figure 3.6 Sketch apparatus of V-funnel test

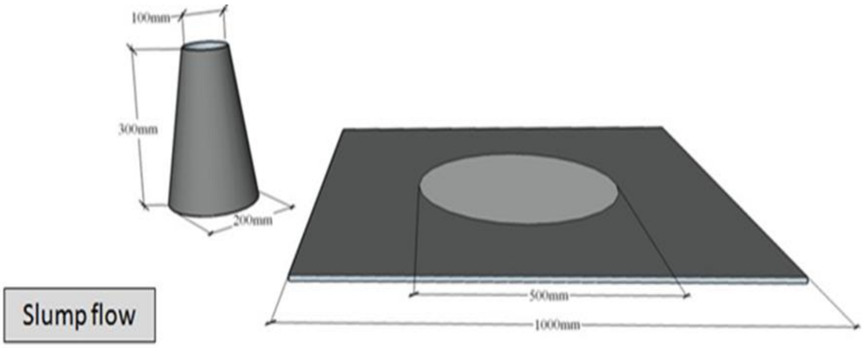


Figure 3.7 Sketch apparatus of slump test

The viscosity of the SCC can be measured by both the T50 slump flow time and V-funnel flow time. Although the direct viscosity cannot be achieved by these tests, the rate of flow relating to viscosity can be described by the results of these tests. V-shaped funnel is used to measure the V-funnel flow time; it is filled with fresh concrete, and then it is allowed to flow out from the funnel, the elapsed time of fully flowing is recorded as the V-funnel flow time. Viscosity classifications with respect to EFNARC (2005) are also presented in Table 3.4 according to the measured V-funnel and T50 slump flow times.

The passing ability of the fresh concrete mix to flow through confined spaces and narrow opening such as areas of congested reinforcement without segregation, loss of uniformity or causing blocking can be measured in terms of L-box test. A measured volume of fresh concrete is allowed to flow horizontally through the gaps between vertical, smooth reinforcing bars and the height of the concrete beyond the reinforcement is measured. Passing ability classes with respect to L-box height ratio values are also given in Table 3.4.

Table 3.4 Slump flow, viscosity, and passing ability classes according to EFNARC (2005)

Class		Slump flow diameter (mm)
Slump flow classes		
SF1		550-650
SF2		660-750
SF3		760-850
Class	T_{50} (s)	V-funnel time (s)
Viscosity classes		
VS1/VF1	≤2	≤8
VS2/VF2	>2	9-25
Passing ability classes		
PA1	≥ 0.8 with two rebar	
PA2	≥ 0.8 with three rebar	

ICAR rheometer, which is shown in Figure 3.8a, was used to measure the rheology of the SCC mixtures. The container, which fresh concrete mixtures were poured up to a height of 305 mm, had the 305-mm diameter. Firstly, the fresh concrete was placed into the container and then four-bladed vane with the diameter, d, of 127 mm and height, h, of 127 mm was positioned in the center of the concrete mixtures. When vane was placed into the fresh concrete mixture, there was 89-mm spacing above and below the vane as shown in Figure 3. 8b. The radii of the inner cylinder, Ri, and outer cylinder, Ro, are 63.5 and 152.5 mm, respectively. External cylinders are equipped with ribs to prevent slippage between the concrete and the steel surface (Saak et al., 2001) breakdown speed and time, number of points, time per point; initial and final speeds are input parameters, which were entered to software to obtain flow curves for each fresh concrete mixture. The vane was first rotated at a speed of 0.5 rps for a breakdown period of 20 sec. Torque measurements were then recorded for seven speeds ranging in descending order from 0.5 rps to 0.05 rps. For analyzing rheological parameters of the fresh concrete properties, Equation 3.1 was used for plotting the flow curves in relative units after the best-fit line was calculated for each mixture.

$$\mathrm{T = G+HN} \tag{3.1}$$

where T, G, H, and N are the torque (Nm), the intercept of this line with the T-axis (Nm), the slope of this line (Nm.s) related to plastic viscosity, and rotational speed (rev/s), respectively (Koehler and Fowler, 2004; Koehler, 2004) When the Bingham model is applied on the rheological behavior of the SCC, some problems may occur since torque-speed relationship is not linear in the SCC. In order to solve these problems, the Herschel-Bulkley model (Equation 3.2), which is the most common non-linear model also having a yield stress, can be used to describe the rheological behavior of the SCC (Larrard et al., 1998).

$$\tau = \tau_0 + K\dot{\gamma}^n \tag{3.2}$$

In the equation, exponent ‘n’ describe the non-linearity and if $n < 1$, $n > 1$, and $n = 1$, the SCC behaves as shear thinning, shear thickening and the Bingham model, respectively. The results obtained from the rheometer were used in this model, and a better fit of the test data compared to the Bingham model was achieved. Equation 3.3 shows the T-N relationship has been transformed to following expression to be able to calculate the fundamental rheological Herschel-Bulkley parameters ($\tau0$, K, and n).

$$\mathrm{T} = \mathrm{G_{HB}} + \mathrm{H_{HB}}\,(\mathrm{N})^{\mathrm{J}} \tag{3.3}$$

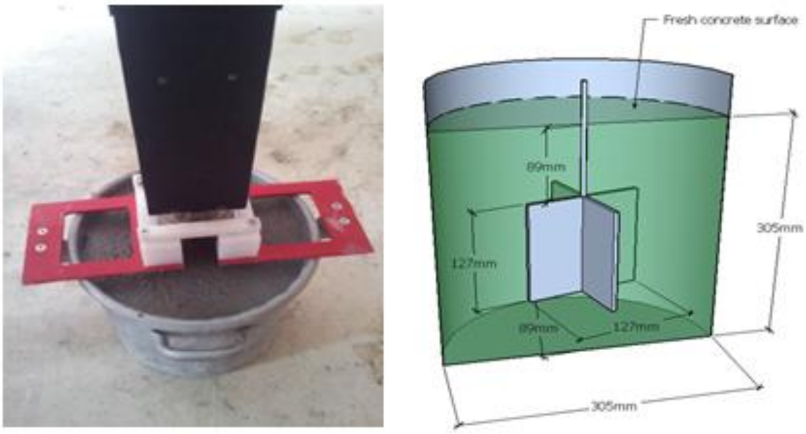
Where G_{HB}, H_{HB}, and J are parameters predicted by Herschel-Bulkley for a T-N relationship. After that, the fundamental rheological Herschel-Bulkley parameters were determined by Equation 3.4, 3.5, and 3.6:

$$\tau_0 = \frac{G_{HB}}{4\pi h}\left(\frac{1}{R_i^2} - \frac{1}{R_o^2}\right)\frac{1}{ln\left({}^{R_o}/_{R_i}\right)} \tag{3.4}$$

$$K = \frac{H_{HB}}{2^{2n+1}\pi^{n+1}h} n^n \left(\frac{1}{R_i^{2/n}} - \frac{1}{R_o^{2/n}}\right)^n \tag{3.5}$$

$$n = J \tag{3.6}$$

The Herschel-Bulkley equations were achieved after the fundamental rheological parameters of the Herschel-Bulkley model were determined.



a) b)

Figure 3.8 Sketch apparatus of V-funnel test a) rheometer and b) detailed schematic representation

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Fresh concrete properties

The passing ability, viscosity, flow ability, and segregation resistance are the four critical characteristics which can specify the filling ability and stability of self-compacting concrete in the fresh state. Each characteristic can be addressed by one or more test methods EFNARC (2005). For instance, slump flow test is used to determine the flow ability while the T_{50} slump flow time and V-funnel flow time tests are used to measure the viscosity. The SCC in the fresh state requires the satisfaction of at least one of above mentioned four critical properties. In order to specify the flow ability, viscosity and passing ability of the manufactured SCCs, slump flow diameter, T_{50} slump flow time, V-funnel flow time, L-box height ratio and L-box T_{20} and T_{40} flow times were measured and graphically depicted.

4.1.1 Slump flow diameter

In the equation, exponent ‘n’ describe the non-linearity and if $n < 1$, $n > 1$, and $n = 1$, the SCC behaves as shear thinning, shear thickening and the Bingham model, respectively. The results obtained from the rheometer were used in this model, and a better fit of the test data compared to the Bingham model was achieved. Equation 3.3 shows the T-N relationship has been transformed to following expression to be able to calculate the fundamental rheological Herschel-Bulkley parameters (τ0, K, and n).The SCC mixtures manufactured in this study had the slump flow diameter changing between 720 and 785 mm. The slump flow diameter was determined by taking the average of two measured diameter of flowed concrete as shown in Figure 4.1. The variation in slump flow diameter with respect to CF volume fraction is illustrated in Figure 4.2. The results indicated that the SCC mixtures, including silica fume had higher slump flow diameters than those did not contain silica fume. Since silica fume has a spherical particle, replacing Portland cement with the silica fume increased the flowability of concrete. For this reason, utilization of silica fume resulted in higher slump flow diameter. However, addition of carbon fiber systematically decreased the slump flow diameter since the carbon fiber in the micro-scale had high surface area. The lowest slump flow diameter of 720 mm was measured in SF0CF15 mix while the highest slump flow diameter of 785 mm was obtained in SF10CF0 mixture. Although decreasing in the slump flow diameter was observed by increasing the CF volume fraction, all results satisfied the EFNARC limitations. Addition carbon fiber more than 1.0% changed the slump flow class from SF3 to SF2. To achieve the acceptable slump flow diameter for the SCC mixtures and to minimize the reducing in the slump flow diameter, superplasticizer content was increased during the study.

Figure 4.1 Measurement of slump flow diameter for SCCs (Control mixture)

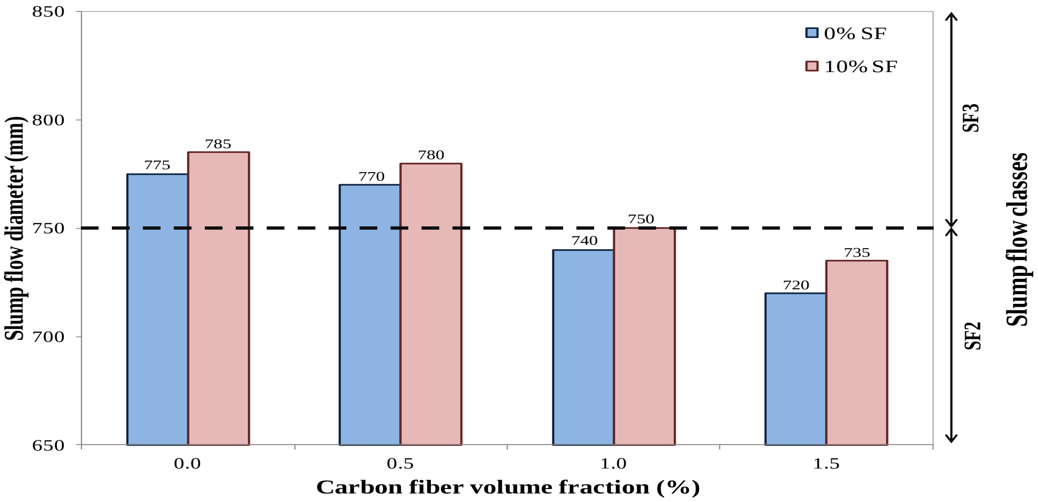


Figure 4.2 Slump flow diameter and slump classes of SCC with respect to carbon fiber volume fraction at different SF contents

4.1.2 T_{50} slump flow and V-funel flow times

T50 slump flow and V-funnel flow times of the SCC mixtures with respect to CF volume fraction respectively are presents in Figures 4.3 and 4.4. In addition, Figure 4.5 demonstrates T50 slump flow time via V-funnel flow time of each mixture regarding to viscosity class according to EFNARC (2005). The results indicated that the silica fume incorporation enhanced both T50 slump flow and V-funnel flow times as in the slump flow diameter. Increasing the CF volume fraction resulted in higher flow time for the SCC mixtures. Utilization of carbon fiber made the fresh concrete more cohesive and viscous due to its particle size. The SCC mixtures produced with 0% and 0.5% CF volume fraction were in VS1 class while the other mixtures were in the VS2. T50 slump flow time results indicated that utilization of carbon fiber more than 0.5% changed the viscosity class of the SCC mixtures from VS1 to VS2.

The similar result was observed in the V-funnel flow time test. Viscosity class according to V-funnel flow time was shifted from VF1 to VF2 when the carbon fiber was added greater than 0.5% in the SCC production. The iteration of T50 slump flow and V-funnel flow times, which is represented in Figure 4.4, illustrated that the SCC mixtures containing 0% and 0.5% carbon fiber were in the boundaries of VS1/VF1 viscosity class specified by EFNARC (2005) while the mixtures containing carbon fiber more than 0.5% were in the boundaries of VS2/VF2.

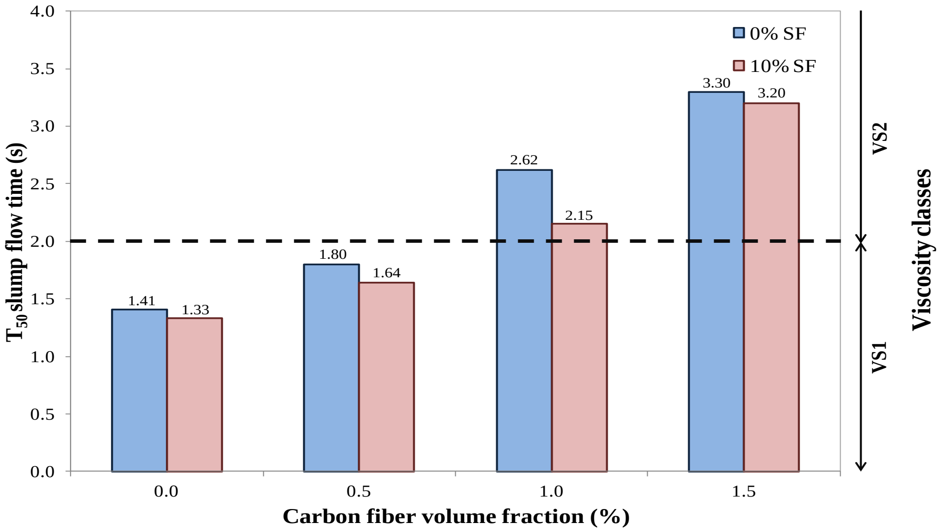


Figure 4.3 T50 slump flow time and viscosity classes of SCC with respect to carbon fiber volume fraction at different SF contents

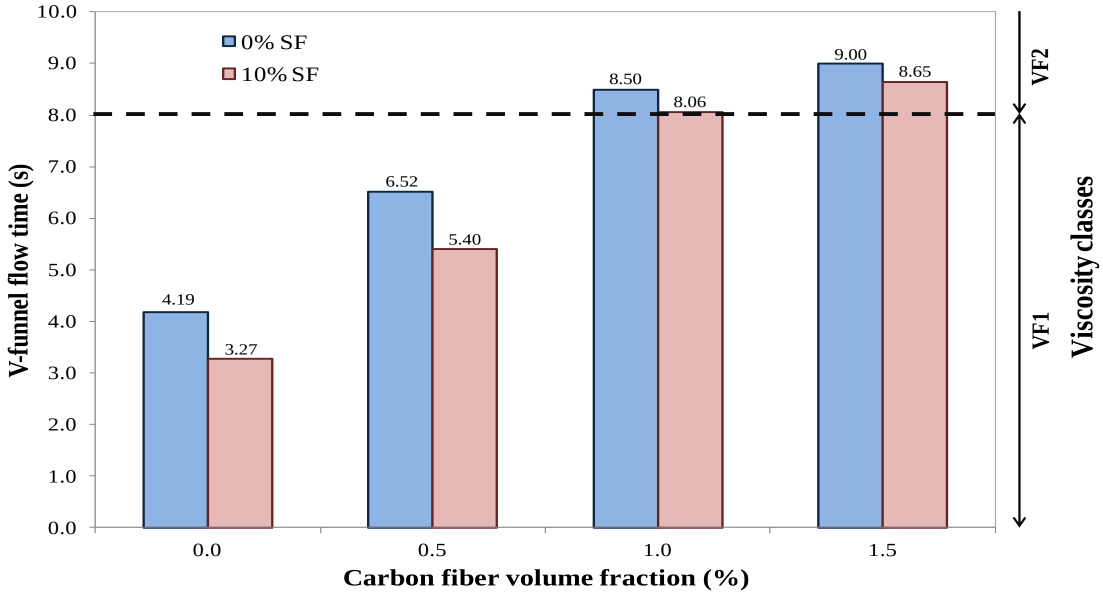


Figure 4.4 V-funnel flow time and viscosity classes of SCC with respect to carbon fiber volume fraction at different SF contents

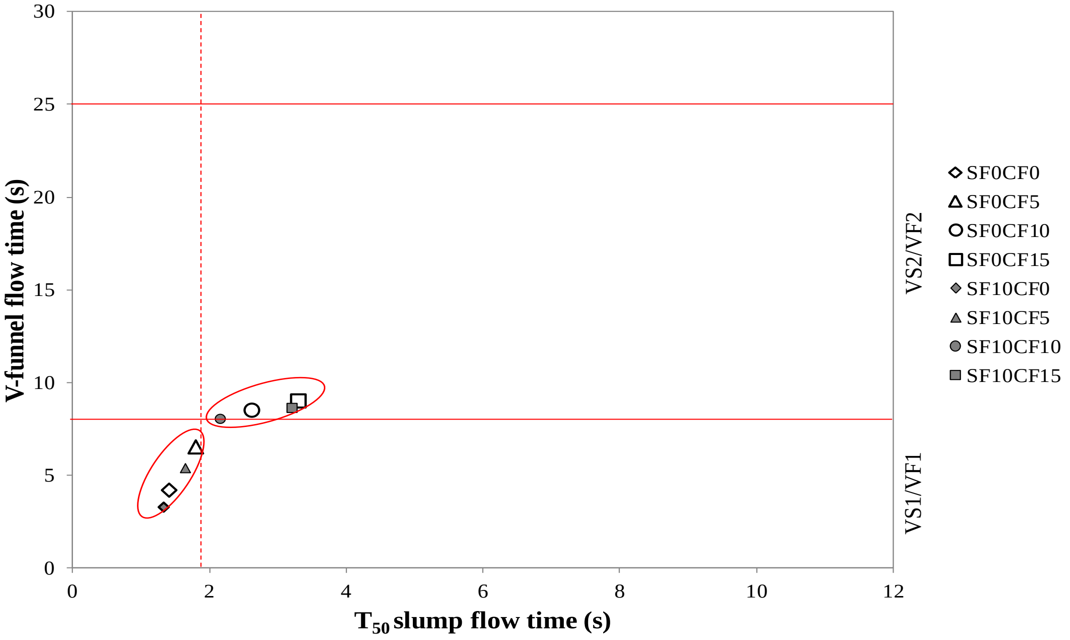


Figure 4.5 T50 slump flow time versus V-funnel flow time for SCC

4.1.3 L-box height ratio

The passing ability of the SCC mixtures in terms of a L-box height ratio by H2/H1 is presented in Figure 4.6. Three bars L-box test was used perform the passing ability of the mixtures. According to EFNARC (2005), three bars, L-box test simulates more congested reinforcement and the ratio obtained from this test must be equal or greater than 0.8 to confirm that the SCC has the passing ability. If the L-box height ratio is

1.0, it can be noted that the SCC has a perfect fluid behavior. According to aforementioned information about the passing ability of the SCC, it can be said that all SCC mixtures produced in this study specify the requirements. It could be clearly seen from Figure 4.6 that incorporating the silica fume improved the passing ability of the SCC mixtures. The L-box height ratio range from 0.878 to 0.929 was measured in this study. Since the CF addition made the SCC mixtures more cohesive and viscous, small amount of decreasing in the L-box height ratio was observed by increasing the CF volume fraction.

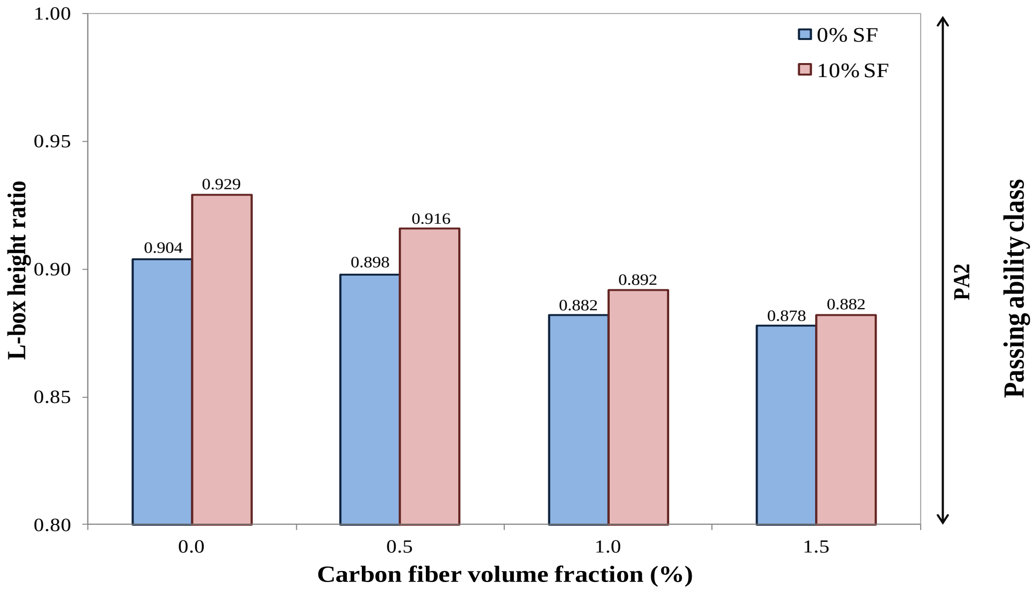
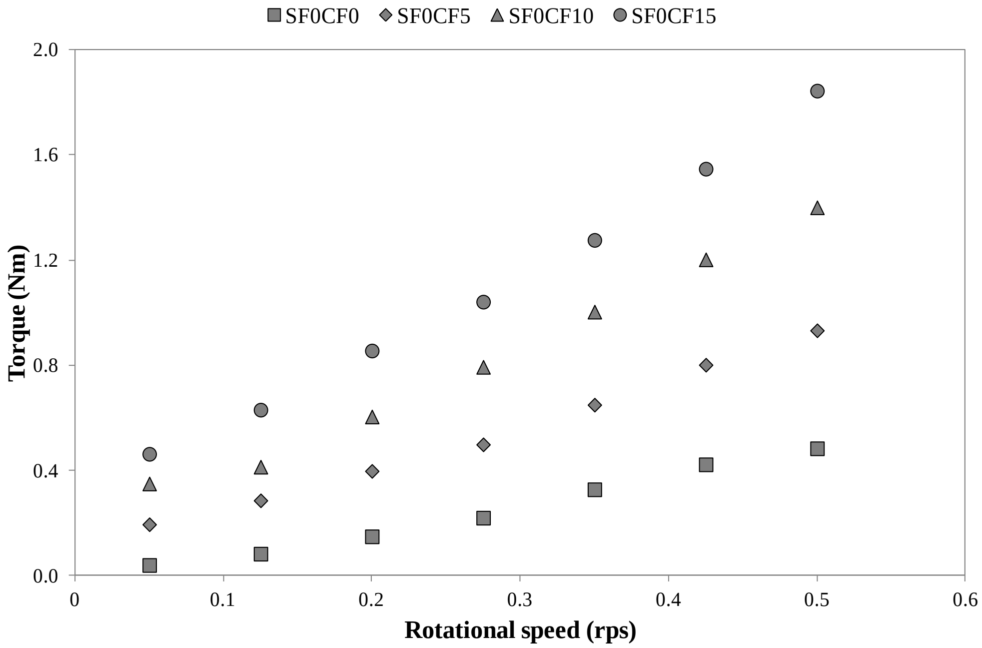


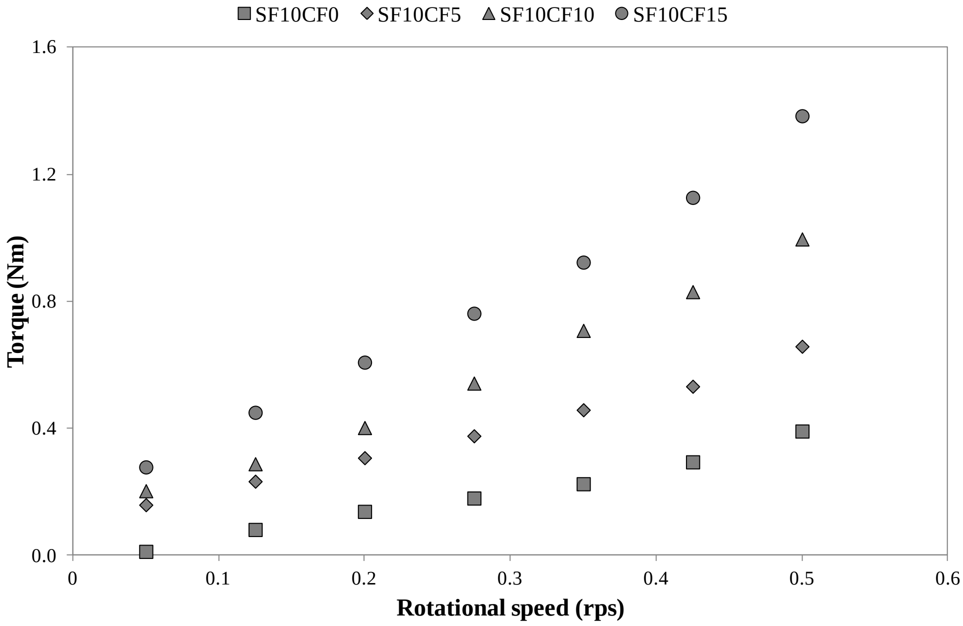
Figure 4.6 L-box height ratio and passing ability classes of SCC with respect to carbon fiber volume fraction at different SF contents

4.1.4 Rheology

The relationships between the torque and the speed obtained from the rheometer are presented in Figures 4.7 (a and b) for the SCC mixtures without and with the SF, respectively. The relationship between the torque and the speed indicated that increasing the CF volume fraction increased the torque values at the same speed value whereas replacing Portland cement with SF resulted in lower torque values. Besides, Herschel-Bulkley model was applied on the torque VS rotational speed. Then, the shear stresses and shear rates were determined and plotted in Figure 4.8 (a and b) for the SCC mixtures without and with the SF, respectively. The results revealed that the SCC mixtures manufactured in this study had to shear thickening behavior. This behavior could be understood from the convex relationship between the shear stress and shear rate values as well as the exponent ‘n’ value of the equation of the Herschel-Bulkley model shown on the Figures 4.8 (a and b). The exponent ‘n’ value that was greater than 1.0 was the indication of the shear thickening behavior. The lower exponent ‘n’ values for the SCC mixtures were determined in the SCC produced with 10% silica fume. The silica fume incorporating decreased the exponent ‘n’ value namely shear thickening. However, use of carbon fiber caused a decrease in the exponent ‘n’ value. Besides, the increasing of CF volume fraction resulted in an increase in the exponent ‘n’ value. Consequently, when the rheology of the SCC was considered, the plastic viscosity could not be given since there was nonlinear relationship between the shear stress and the shear rate values.

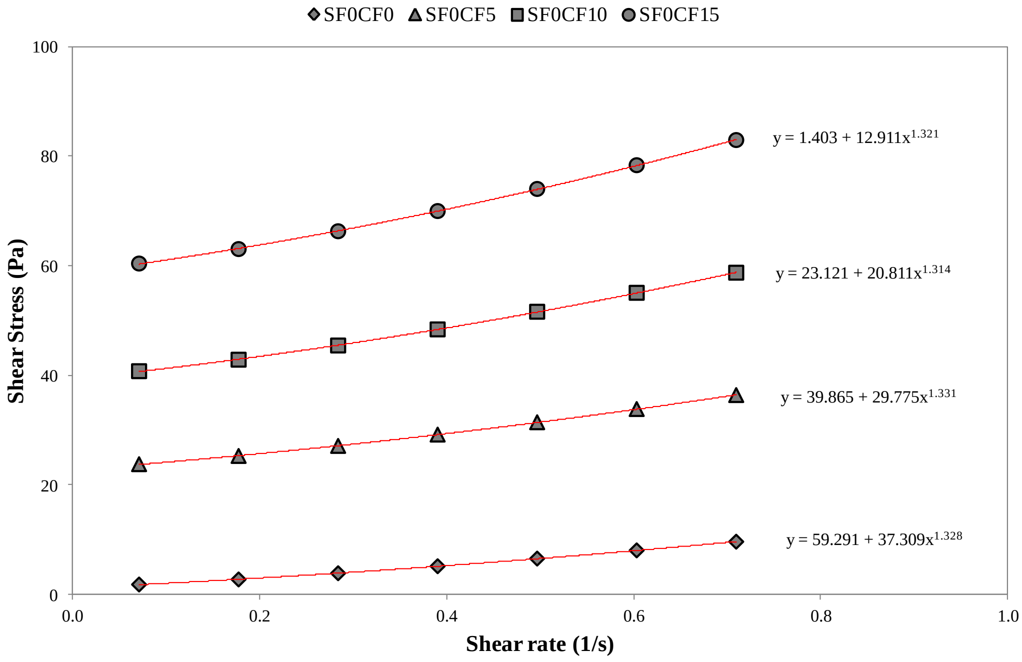


(a)

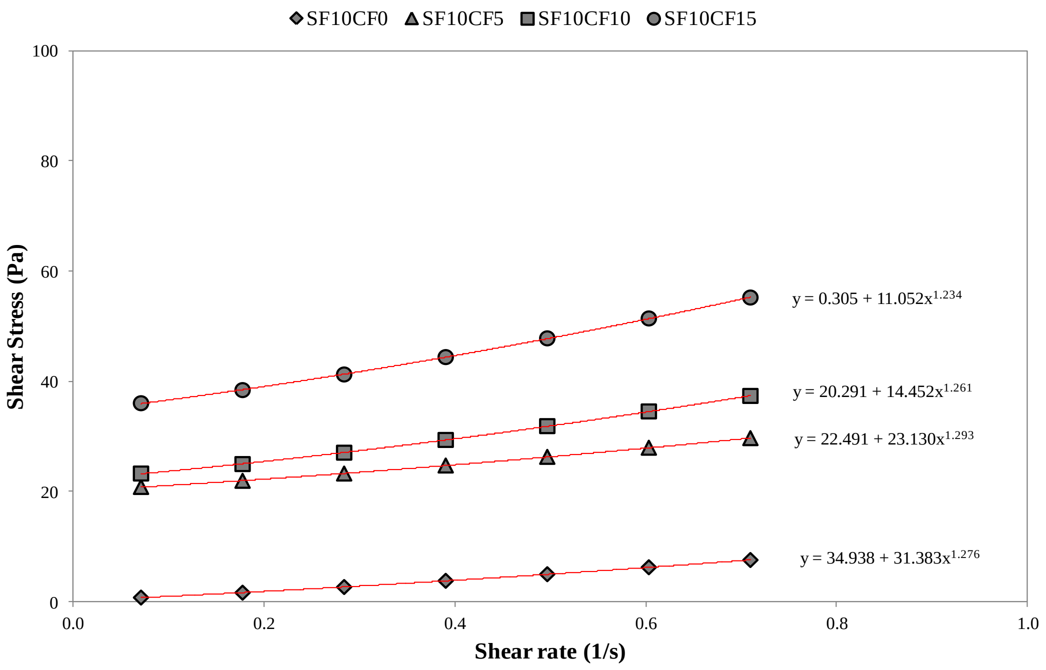


(b)

Figure 4.7 Torque versus rotational speed obtained from the rheometer for carbon fiber reinforced SCC with: a) 0%, and b) 10% SF contents



(a)



(b)

Figure 4.8 Application of the Herschel-Bulkley model on the rheological data for the carbon fiber reinforced SCC with: a) 0%, and b) 10% SF contents

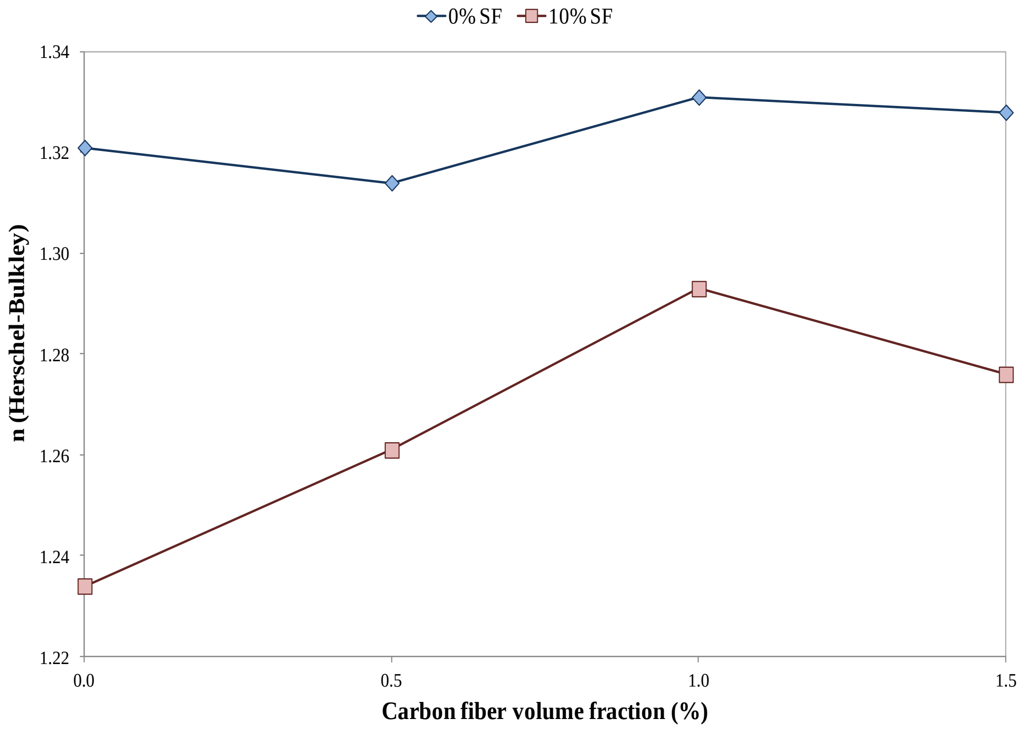


Figure 4.9 Variation in exponent ‘n’ values (Herschel-Bulkley) for SCCs with different carbon fiber volume fraction and SF contents

CHAPTER 5

CONCLUSIONS

Based on the aforementioned experimental findings of this study, the following conclusion can be drawn:

- The slump flow diameter of the SCC was decreased by the adding carbon fiber and increasing its content. The SCC mixtures produced with 0 and 0.5% carbon fiber volume fraction were in the SF3 class, but those manufactured with 1.0 and 1.5% carbon fiber volume fraction were in the SF2 class for both silica fume contents of 0 and 10%.
- T_{50} slump flow and V-funnel flow times of the SCCs were significantly affected by carbon fiber utilization. The SCC mixtures were in the boundaries of VS1/VF1 viscosity class at carbon fiber volume fractions of 0 and 0.5%. However, the SCC mixtures were in the boundaries of VS2/VF2 when carbon fiber was used more than 0.5% volume fraction.
- The passing ability of the SCCs in terms of the L-box height ratio was decreased by addition of carbon fiber and increasing its content. Although there was a reduction in the L-box height ratio by adding of carbon fiber and increasing its content, all mixtures produced in this study had the acceptable L-box height ratio according to EFNARC.
- The shear thickening behavior was observed for the SCC mixtures produced in this study when the Herschel-Bulkley model was applied on the torque and speed values obtained from the rheometer. The use of carbon fiber increased the exponent ‘n’ value that indicated the rheological behavior of the concrete whereas the silica fume incorporating resulted in the increasing of the exponent ‘n’ value.

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