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MECHANICAL AND DURABILITY PROPERTIES OF SELF-COMPACTING CONCRETE MADE WITH PROCESSED WASTE RUBBER GRANULES

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Mechanical and Durability Properties of Self-Compacting Concrete Made with Processed Waste Rubber Granules

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Supervisor

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ABSTRACT

MECHANICAL AND DURABILITY PROPERTIES OF SELF-COMPACTING CONCRETE MADE WITH PROCESSED WASTE RUBBER GRANULES

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Thestudy presented herein was carried out to investigate the mechanical and durability characteristics of self-compacting concretecontaining waste coarse rubber aggregates (WRA). Two different series of self-compacting rubberized concrete (SCRC) mixtures were designed with a constant water–cementitious material (w/cm) ratio of 0.32 and total cementitious materials content of 550 kg/m3. The first group of mixtures was incorporated binary cementitious blends of 20% flyash(FA)and 80% Portland cement. However, the second series of the mixtures incorporated Ternary cementitious blends of 20% FA with 10% silica fume(SF) and 70% Portland cement. To develop the RSCCs, medium aggregate was substituted by WRA at five designated contents of 0%, 10%, 20%, 30% and 40% by volume in both series of concretes. Totally, 10 concrete mixtures were cast and tested for mechanical and durability related properties suchascompressive strength, splitting tensile strength, modulus of elasticity, sorptivity, chloride ion permeability, gas permeability and fracture energy.The tests were conducted at 28 and90 days after casting.Test results demonstrated that using the rubber particles improved the fracture and ductile properties, whereasaggravated all other measuredproperties of self-compacting rubberized concretes (SCRCs). However, with the addition of silica fume in to the mixes all mechanical and durability propertiesenhanced, depending mainly upon rubber content.

Keywords: Waste coarse rubber aggregate; Mechanical properties; Durability properties; Self-compacting rubberized concrete; Silica fume

ÖZET

İŞLENMİŞATIK PLASTİK GRANÜLİÇEREN KENDİLİĞİNDEN YERLEŞEN BETONLARIN MEKANİK VE KALICILIK ÖZELLİKLERİ

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Burada sunulan çalışma, atık kaba lastik agregası içeren kendiliğinden yerleşen betonların mekanik ve kalıcılık özelliklerini incelemek üzeregerçekleştirildi. İkifarklıkendiliğindenyerleşenlastiklibetonserisi 0.32 sabitsuçimentooranıvetoplam 550 kg/m^{3}çimentomsumalzememiktarındatasarlandı.İlk gruptakikarışımlarda %20 uçucukülve %80 Portland çimentosuolmaküzereikiliçimentomsukarışımkullanıldı.Ancakikincigruptakikarışımlarda %20 uçucukül, %10 silisdumanıve %70 Portland çimentosuolmaküzereüçlüçimentomsukarışımkullanıldı. Her ikibetonserisinde de kendiliğindenyerleşenlastiklibetonlarıngeliştirilmesiiçinortaagregaatıklastikagregasıyla hacimce %0, %10, %20, %30 ve %40 olmaküzerebeşmuhtevasındayerdeğiştirildi. Toplamda 10 betonkarışımıdöküldüvebubetonlarınbasınçdayanımı, yarmadaçekmedayanımı, elastisitemodülü, kırılmaenerjisi, kılcalsugeçirimliliği, klorüriyongeçirimliliğive gas geçirimliliğigibimekanikvekalıcılıközellkleri test edildi.Deneylerdökümden 28 ve 90 günsonragerçekleştirildi. Test sonuçlarılastikparçalarıkullanımınınkırılmavesünekliközelliklerinîiyileştirdiğini, kendiliğindenyerleşenlastiklibetonlarındiğerölçümüyapılanözelliklerininiisekötüleştirdiğinigösterdi. Ancaksilisdumanınkarışımlaraeklenmesibütünmekanikvekalıcılıközelliklerinidahaçoklastikmiktarınabağlıolarakgeliştirdi.

Anahtarkelimeler:Atıkkabalastikagregası; Mekaniközellikler; Kalıcılıközellikleri; Kendiliğindenyerleşenlastiklibeton; Silisdumanı.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS/ABBREVIATIONS

a	notch depth of beam
A	Cross-sectional area of the sample
ACI	American concrete institute
ASTM	American society for testing and materials
B	Width of beam
CC	Conventional concrete
CM	Cementitious material
CRM	Cement replacement material
D	Diameter of cylinder mold
E	Modulus of elasticity
EFNARC	European federation of national associations representing for concrete
FA	Fly ash
$F_{flex.}$	Net flexural strength
Fst	Splitting tensile strength
G_f	Fracture energy
GGBFS	Ground granulated blast furnace slag
HPC	High performance concrete
HRWRA	High range water reducing admixture

K	Gas permeability coefficient
L	Height of sample
L	Length of cylinder mold
LVDT	Linear variable displacement transducer
m	Mass of beam
NCA	Natural coarse aggregate
NFA	Natural fine aggregate
NVC	Normal vibration concrete
P1	Inlet gas pressure
P2	Outlet gas pressure
PC	Portland cement
P_{max}	UlimateFracture load
PP	Polypropiline plastic
Q	Volume flow rate
RCPT	Rapid chloride permeability test
RILEM	Recommendations for the testing and use of constructions material
S	Span of beam
SCC	Self-compacting concrete
SCRC	Self-compacting rubberized concrete
SF	Silica fume
SP	Superplasticizer

SSD	Saturated surface dry
U	Length of beam
VMA	Viscosity modifying admixture
W	Depth of beam
w/b	Water – to - binder ratio
w/c	Water –to-cement ratio
Wf	Total amounts of fracture works
W_o	Area under the load–displacement curve
WRA	Waste coarse rubber aggregate
δ	Deflection
η	Viscosity of oxygen

CHAPTER 1

INTRODUCTION

1.1 General

Many types of construction materials are used forconstructing infrastructure. Concrete,certainly, is the most widely used of all building materials and it is the massiveuser of natural sources such as water, sand, gravel and crushed rock. Portlandcement is the commonly used binder for current concrete mixtures.In addition to the largeamount of natural resources needed in the manufacturing of cement, large amount ofenergy is required for the process, which results in large amount of CO_2transmission intoour atmosphere. Poor workmanship, quality of materials and management of ourinfrastructure are the main sources of early deterioration in concrete structures. It hasbeen proved that normal concrete of the past does not comply with the needs of structures inharsh and evenmoderateenvironments. Deterioration due to poor durability is an issue and it isessential that the construction industry use more sustainable materials to increase theability of recent structures (Lambros and Vasilios, 2004).

The required workability for molding concrete be influenced by the type of construction,a selection of placement, compacting methods, and the complex shape of the reinforcement.With the increased use of blocked reinforced concrete there is a growing need forhigh flowable concrete to confirmsuitable filling of the formwork. Congested elementsconfine the access of vibrators needed to sufficiently consolidate normal concrete.Furthermore, excessive vibration can cause undesirable segregation and bleeding in nonflowableconcrete. Therefore, skilled labour and accurate quality control are required toensure adequate compaction and sufficient homogeneity of the concrete to prevent thedeteriorationof infrastructure. Ensuring correct placement and consolidation of nonflowableconcrete rises the cost of construction and time required to complete aproject.

Self-compacting concrete (SCC) is a high flowable concrete and can flow into placesunder its self weight. SCC obtain a good consolidation without needto any compaction and without defects due to segregation and bleeding. SCC can be working to facilitate the filling of congested structural elements within a limited area, it can beused as a repair material for structural reconstruction, and it can also be used to castnon-congested elements to decrease construction time and increase the overall productionof a project. SCC would also decrease labour cost, and improve the working environment byeliminating the noise and pollution caused by vibrators(EFNARC, 2005).

SCC was first produced in Japan in the early 1980’s. The fundamentals of the development wereprescribe by three main factors, one being the need for flowing concrete to satisfysuitable filling within the complex reinforcement design in seismic members. Othersare the reducingthe number of laboursin Japan and the need to decrease costand time of construction. With the increasing use of concrete in special architecturalforms and closelyspaced rebars, it is very important to create concrete that confirms the ability of the appropriate filling and structural performance and durability good enough (Hayakawa et al., 1993).

Aggregate typically accounts for 65‑80% of the concrete volumeand it has a significant role in concrete characteristics such asworkability, strength, volume stability and durability. Theuse of waste materials as aggregates in concrete mixtures canconsume large amounts of waste materials. This led to solve problemsof lack of aggregate on construction places and decrease environmentalproblems related to aggregate stocks and waste disposal. There is agrowing interest in using waste materials as aggregate and significantresearch has been undertaken on the use of many differentmaterials as aggregate replacements. Among the materials investigatedare granulated coal ash, blast furnace slag, fibre glass waste materials,waste plastics, rubber waste and sintered sludge pellets(Saikia and Brito, 2011) .

Over the years, and the disposal of waste rubber has come to be one of the serious environmental problems. Landfilling has become unsuitabledueto the rapid reductionofavailable sites for waste disposal. Large amounts of wasterubbers are produced every year all around the world. These stockpiles are hazardous because of the potential environmental risks, also from fire hazards and provide a breeding ground for rats, mice, and vermines (Chandra, 1997; Siddique, 2008)

Reusing of the waste rubber becomes main factor to solve environmental problems. To use this waste in construction framework which is one of the most consumed raw materials is very important in the field of environmental protection and sustainability and economic gains (Emiroğlu and Yildiz, 2010, Kuszczak and Alpaslan, 2011)

The brittleness and low tensile strength of cement-based materialsare disadvantageous to their durability (Turatsinze et al., 2006). Researchers are tryingto reduce brittleness of concrete and they have been working onthe possibility to make the concrete tough by introducing wasterubber phases between the traditional components (cement, water,and aggregates).The idea of developingSelf Compacting Concrete (SCC) including rubberaggregates is an innovative approach to combine the advantagesof both SCC and rubberised concrete. Toachieve therequired self-compacting properties, the new materialSelf Compacting Rubberised Concrete (SCRC), needsa slightly higher super plasticiser than conventional SCCat the same water/powder ratios(Bignozzi and Sandrolini, 2006). Even though thistechnology has the potential for obtaining an interesting mechanical behaviour.Paststudies suggest that the partial replacement ofcoarse or fine aggregate of concrete with waste rubbers canimprove properties such as abrasion resistance, shockabsorption, vibration absorption and ductility(Topçu and Nuri, 1997; Raghavan et al., 1998; Bignozzi et al., 2000).

Several of the cement replacement materials (CRM) have optimistic effects on SCC; fresh and mechanical properties. Likewise, silica fume (SF) involves less water demand as equated to microwave incinerated rice husk ash (MIRHA) for attaining the alike fresh properties. SF was used in the SCC mix as the type of CRM and can recover the workability characteristic of the SCC mix as well as enhancement of compressive strength (Fathi et al., 2013; Hassan, 2012; Dehwah, 2012). SF is an industrial by-product of silicon metal or some ferrosilicon alloys. The fume which has a high content of shapeless silicon dioxide and consists of very fine spherical particle particles (0.1 - 0.2 μm) is composed from the sewage gases absconding since the furnace. SF which is generally used in cement based systems, contain 85 to 98% silica, and in itself, does not have any cementitious properties but when reacts with Ca(OH)2 on hydration of cement produces the gel i.e. Calcium-silicate-hydrate (C-S-H) which has good contentious properties. SF is known to improve both the mechanical characteristics and durability of concrete (Srivastava et al., 2012).

The main objective of the thesis presented herein is to investigate the SCC characteristicsincorporated waste coarse rubber aggregates (WRA). For this purpose, an experimental program was conducted. In this study, natural medium aggregates of conventional SCC were partially substituted by WRA at five volume fractions from 0% to 40% by 10% increments.Toreduce the negative effect of WRA on the workability and to improve hardened and durability characteristics of SCRCs, fly ash (FA)with silica fume (SF) was used in partialreplacement of cement at 20% and %10 respectively. Thus, a total of ten different SCRC mixtures were designed with constant water-binder ratio (w/b) of 0.32 and the overall binder contented of 550 kg/m^3. Hardened characteristics of SCRCs were tested for indirect tensile andcompressive strength, elastic modulus, sorptivity, chloride ion permeability, gas permeability. Moreover, fracture energy was determined for each SCRC.

1.2 Research Significance

A lot of rubbers is produced worldwide. It is not possible to discharge the rubbers in the environment because they decompose very gradually and cause lots of pollution. So, it is required to have a significant use of these wastages. These waste materials can be used to improve some mechanical properties of concrete. Addition of rubber to concrete results in the improvement of some mechanical and dynamical properties, such as more energy adsorption, better ductility, and better crack resistance. The idea of developing Self Compacting Concrete (SCC) incorporating rubber aggregates is an innovative approach to combine the advantages of both SCC and rubberised concrete.

1.3 Outline of the Thesis

Chapter 1gives the explanation about objective and aim of this study.

Chapter 2 presents a review of the literature and general background on the SCC, advantages ,applications and properties of SCC. The influence of WRA on the mechanical properties and durability, of SCC was given.

Chapter 3 includes the experimental program conducted throughout this study. Properties of cement, aggregates, mineral and chemical admixture used in the concrete production as well as the tests on hardened properties of SCRCs are described.

Chapter 4 provides the results of testing program. Moreover, how the replacement of waste rubber aggregate affect the mechanical, durability and fracture properties of self-compacting rubber aggregate concrete areexplained in this chapter. List of results, figures, evaluation are presented and discussed.

Chapter 5 gives conclusions of the thesis.

CHAPTER 2

LITERATURE REVIEW AND BACKGROUND

2.1 Self-compacting concrete

Self-Compacting Concrete (SCC) is a highly flowable High Performance Concrete(HPC) that can flow everywhere inside the formwork under its individual weight and achieve good consolidationwithout internal or external vibration and without showing defects due to segregationand bleeding (Lachemi et al., 2003).

Concrete that needs little vibration or compaction has been used in Europe since the early 1970s but self-compacting concrete was not established until the late 1980's in Japan. In Europe it was probably first used in civil works for transportation networks in Sweden in the mid1990's. The European countries funded a multi-national, industry lead project "SCC" 1997-2000 and since then SCC has found increasing use in all European countries (EFNARC, 2005).

Durability of structures is a vital issue with conventional concrete. Thus, highperformance materials are need to build more durable structures. adequate fillingand consolidation associated with the use of SCC can decrease voids and inadequate bonding of concrete to the reinforcement, which in turn, can improve the durability oftheconcrete and decrease future rehabilitation costs.

The removal of vibrating equipment make better environment on and near construction and precast sites where concrete is being placed, decreasing the exposure of workers to noise and vibration (Byun et al., 1998).

The process for achieving self-compactability contains not only high deformability of paste and mortar, but also resistance to segregation between coarse aggregate and mortar when the concrete flows through the conjested reinforcing bars. (Okamura and Ozawa, 1995)have employed the following methods to achieve self-compactability.

(1) smaller coarser aggregate content compared to convential concrete.
(2) Small water-powder ratio.
(3) Use of superplasticizer.

The enhanced construction practice performance, with combined the health and safety benefits, make SCC a veryinteresting solution for precast concrete and civil engineering construction (Figure 2.1).

Figure2.1Casting precast element of SCC (EFNARC, 2005)

2.2 Advantages and Disadvantages of self-compacting concrete

According to EFNARC (2002), investigated that the SCC has proved beneficial economically because of a number factors which include the faster construction, reduction manpower in the site, safe working environment, complete and uniform consolidation, and reduction noise levels due to absence of vibration. As well, itinvestigated that the concrete after casting has better surface finishes and increased bond strength between steel bar surface and concrete, with improving the durability, other advantages for SCC is the greater freedom in design (Chalhotra, 2011). SCC involves higher admixture and powder contents than normal vibration concrete (NVC);

therefore, the price of material is more expensive, which mean that the superplastisizer is one of these mainly admixture (Concrete Society and BRE, 2005; Miao, 2009).

Comparing to equally grad NVC in almost all cases the increasing variety in cost ranged from 20% to 60%. (Nehdi et al., 2004; Ozawa, 2001). Nevertheless, increased material cost in very big structure according to using SCC was balanced by saving in construction time and labour costs (Billberg, 1999). In any compound sandwich structure, the basic welfare of SCC is whole demonstrated in molding SCC beside NVC in sheets (Okamura and Ouchi, 2003a; Ouchi, 2001; Ozawa, 2001). Comparison of SCC and NVC belonged to sensitivity of material variation; the SCC requires higher quality control due to existence of powders and admixtures (Walraven, 1998).

2.3 Applications of self-compacting concrete

Lacombe et al., (1999) examined the application of SCC as an overhead repair material.The study tested three types of repair materials such as normal concrete, SCC andshotcrete. Three concrete blocks were repaired at a depth of about 40 mm onone surface of every block. The SCC used in the experimentationinvolved a Viscosity-Modifying Agent (VMA) to decrease bleeding and segregation in the mixture. Afterseven days from the repairs, explanations were made for each repair method. Resultsshowed that thenormal concrete did not have suitable rheological properties andfilling capacity to be used as an overhead repair material. It also developed largesegregation and large air pockets. This methodrequired skilled labour and wasexpensive.SCC performed well as a repair material making a good bond and demonstratedgood rheological properties important for a quality repair material. But unfortunately, SCCwas costly due to the use of chemical admixtures. Furthermore, labour was not amainreason in the placement of the SCC as it consolidated under its own weight.Shotcrete bond to old concrete was practically perfect, but skilled labour was required toachieve the work and the cost was increased significantly. The investigation also recommendedthe need for more researches to develop cost-effective SCC in order to increase its useas a repair material.

Additional applications for SCC as a repair material were defined by (Campion and Jost, 2000). SCC was used to repair a chloride-induced deteriorated cast-in-place bridge constructedin the 1960’s in the Swiss Alps. The concrete structure had lost a significantquantity of concrete and steel reinforcement on its underside. Formwork and placement of concrete followed the replacement of the steel reinforcement below the deck. The only poured concrete available to accommodate the job at hand was SCC, and it was pumped in the formwork through the underside. Air holes were drilled at the top of the deck to permitthe release of pressure generated when concrete is pumped in the formwork. SCC allowed the project to be completed on time while keeping the required concrete quality throughout the entire project (Campion and Jost, 2000).

Khayat and Ai'tcin (1999)studied projects in Canada where SCC was used. Thesecontained within the rehabilitation of the Webster parking garage in Sherbrooke, therehabilitation of the Beauhamois Dam near Montreal, the casting of experimental residential basement walls, and the construction of a reaction wall at the Universite de Sherbrooke. The use of SCC in these projects displayedSCC to be an effective material for the repair of damaged structural sections. SCC also improved reliability and durability of newly constructed concrete walls.

One of the most important use of SCC was the two anchorages ofAkashi-Kaikyo Bridge opened in April 1998 in Japan (Ouchi and Hibino, 2000),a suspension bridge with the longest spanin the world, approximately 1991 meters (Figure 2.2). The volume of the cast concreteintwo anchorages was about 290000 m3. ANew construction system, which made full use of the performance of SCC, was introduced for this. The concrete was mixedat the batching plant on the site and was pumped out of the plant. It was transported 200 meters through pipes to the casting site, where the pipes were arranged in rows of 3 to 5 meters a part. The concrete was cast from gate valves locatedat 5-meter intervals along the pipes. These valves have been controlled automatically so that a surface level of the cast concrete could be maintained. In the final analysis, the use of SCC decreased the anchorage construction period by 20%, from 2.5 to 2years.

Figure 2.2 Akashi-Kaikyo Bridge, Japan (Ouchi and Hibino, 2000).

Li (1995) discussed the use of SCC in Japan and the competitive edge gained by the firms when producing their own. Two projects in particular were highlighted as examples. One being the Kiba-Park Large Bridge, a 151-m cable-stayed prestressed concrete bridge, only required two workers to pour 650 m^3 of SCC in nine months. The incentive to use SCC was the difficulty and high labour cost of placing normal concrete in heavily reinforced concrete structures. The second was a 70-storey building, the tallest high-rise in Japan, that used 885 m^3 of SCC pumped into steel tubular columns. The concrete was pumped in from the bottom at a maximum filling height of 40 m.

2.4 Mixture proportioning of self-compacting concrete

SCCgenerally has a higher content of finer particles and better flow characteristics than normal vibrated concrete. It has three basiccharacteristics at fresh level, i.e. passing ability, segregation resistance, and filling ability. However, its mixture constituents are same to other concretes. SCC consists of cement, water, fine and gravel aggregates, chemical andmineraladmixtures. SCC can be influinced by the physical properties of constituents and mixture quantities. The mixture proportioning is based on making a high level of flowability while maintaining a low W/Cm. This is achieved by adding high-range water-reducing admixtures (HRWRA) combined with other admixturesfor instance VMA to confirm homogeneity of the mix(Campion and Jost 2000).

A different ways for mix designofSCC was recommended by (Okamura and Ozawa, 1995). In this method:

1. Natural Coarse aggregate content is fixed at 50% of the solid volume.
2. Fine aggregate is placed at 40% of the mortar volume.
3. W/b ratio by volume is selected at 0.9 to 1.0 depending on characteristics of the cementitious materials.
4. Superplastisizer quantity and the final W/Cm ratio are determined so as to ensure the self-compactability.

2.5 Properties of materials

Most materials suitable for normal vibrated concrete can be use to produceSCC, but they produce more influences of the fresh characteristics of SCC than on those of NVC.

The types and the characteristics of the ingredients in SCC and their influences on thefreshand hardened properties are summerized in this part.

2.5.1 Cement

Portland cement is considered as a highly product of energy-intensive. Also some drawbacks regarding that the concrete‟s properties which have educe those negative impacts, the possible requirements of powder content shbeen explored as the contents of cement, which exceeded an identified value. To could be increased in SCC regularly met by use of basic additions (Turk, 2012). Accordingly, multiples essential studies were empirically achieved through the use of diverse additions for particular cement‟s replacement in SCC or self-compacted mortar such as slag, basalt powder, fly ash, silica fume, and limestone powder. Type I-Portland cements is compatible to ASTM C150 (2002) in the current study, the materials of cementitious used which ordinary Portland cements (CEM-I-42.5) compatible to ASTM C150 (2002).

As stated by the European guidelines for SCC (EFNARC, 2005), all cementsthat are conformed to EN 197-1 can be used.

2.5.2Cementitious materials

SCC typically needs a high proportion of powder. If only the use of cement, SCC has a high cost and vulnerable to attack and thermal cracking. Therefore it is necessary to replace some of the cement additives such as fly ash, silica fume, GGBS or limestone filler.

Additions are extremelyfine materials used in concrete to advancecertain characteristics or to attain certain properties.

The main effects of some additives that are commonly used in fresh and hardenedproperties of SCC are summarised below:

- SF is an extremely fine powder and expensive. It increases the shear stress and the plastic viscosity, thus significantly decreasing the slump flow and segregation (Carlsward et al., 2003). SF decreased the ionic strength of the pore solution leading to a reduced consistence loss (Bonen and Sarkar, 1995). The hardened properties and the durability of concrete are also improved. Modest quantities, up to 5%, have been used in SCC (Khayat and Aitcin, 1998).

- FA is an effective addition for SCC that increased cohesion of concrete because of its spherical particle shape; FA improves the filling ability of concrete but leads to low early strength (The Concrete Society and BRE, 2005). Various fineness of FA have been used. An ultra pulverised fly ash of Blaine surface area 500~600 m2/kg can lead to an increase in the viscosity and a decrease in the possibility of segregation, thus making a SCC with satisfactory properties and with a lower powder content (Xie et al., 2002). FA contributes to the strength at late age due to its pozzolanic nature.

- Limestone powder is a common addition in SCC. Limestone powder increases the yield stress but has little influence on the plastic viscosity and the slump flow (Carlsward et al., 2003).

Limestone powder is only a filler in the SCC which does not contribute incement hydration (Ye et al., 2007). On the other hand, it has been statedthat although limestone is not pozzolanic, it can still contribute to strength (Edamatsu et al., 1999; Pera et al., 1999). Because finely ground limestone particles act as nucleation sites for cementhydration, thus accelerating early age strength development.Limestone powder may decrease the drying shrinkage of the concrete anddecrease the water absorption (Felekoglu, 2008).

Table 2.1Strength of SCC with fly ash and limestone powder (Mnahoncakova et al., 2008).

	W/b by WT.	COMPRESSIVE STRENGTH (MPA)(day)				
		1	3	7	28	90
SCC with 40% limstone powder	0.28	13	36	44.3	54	64
SCCwith 40% fly ash	0.24	8	21	33.3	43	63

Table 2.1 (Mnahoncakova et al., 2008) displays two SCC mixuresincluding limestone dust and FAseparately. Limestone is more finerthan FA. Both particle sizes are in the range of 0 ~ 300 microns, but the cumulative percentages passing 20µm are 62.6% and 31.2% on the limestone and fly ash respectively. As shown SCC with limestone it has a higher strength with fly ash up to 28 days and similar results in 90 days; and increases the strength of 28 to 90 days is 18% and 46% for SCC with limestone and fly ash respectively. This shows that the limestone powder contributes to a higher strength in the early ages and fly ash improves the strength of the long-term.

2.5.3 Aggregate

It is known that continuous grading of aggregates, Which results in abetter deformation capacity, is better suitable for SCC. In fact, It has been using a differentaggregate types, sizes and shapes in SCC. Figure 2.3 (Aarre and Domone, 2004)demonstrates that SCC can be produced with significantly different gradings ofaggregates.

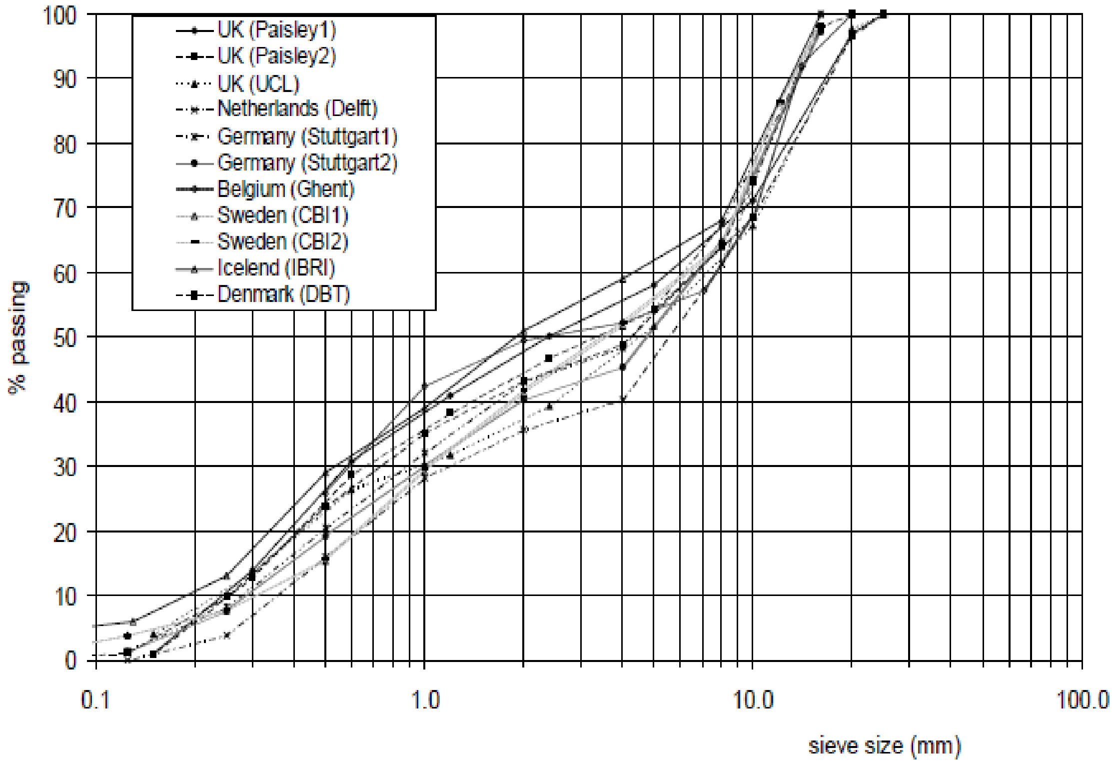

Figure 2.3Aggregate size distribution used for successful SCC by Testing SCC project (Aarre and Domone, 2004)

The combinationof fine, coarse aggregates and graded aggregates increases the packingdensity which leads to a reduced superplasticiser dosage and paste volume(Khayat et al., 1999).This also helps segregation resistance because smallaggregates can resist the settlement of medium size aggregates which in turnwill resist the settlement of large aggregates (Bonen et al., 2007). Better packingenhances strength and durability because of the minimised voids and densestructure. The denser the concrete, the more effective the paste is, whichlubricates and fills the voids in concrete to provide consistence and strength.

2.5.3.1 Sand (fine aggregate)

Sand with grades well distributed, small spherical in shape and absorption are useful for SCC.Therefore, the natural rounded of clean sand may be better compared to crush angular sand. In reality, local accessibility decides wich type of sand used in SCC (Skarendahl, 2003).baddistributed particles and shaped fine aggregatecaused byincreasing the amount of paste or viscosity (Westerholm et al., 2008).

Billberg (1999) stated thatThe variations in the sand did affect the performance of the SCC by showing that the effect of aggregate fineness of the slump flow, and the fill heigh of U-box varied with different moisture contents of theaggregate.

2.5.3.2 Coarse aggregate

Coarse aggregate has a significant role when studying the fresh and hardened properties; SCC is considered as two-phase material of coarse aggregate and mortar in different design mix studies.

In fact, an investigation of 63 case studies found that the choice of crushed or natural gravelaggregates depends on local availability (Domone, 2006b).

Blocking takes place easily if the size of the aggregate is larger than therebar spacing. Most SCC applicationswere used coarse aggregate witha maximum size in the range of 16-20 mm depending on local availability and practice (Domone, 2006b).

Okamura and Ouchi (2003b) reported that the decrease in filling ability due to an increase of the coarse aggregate content in concrete occurred regardless of its shape. It is known of blockage is small when the coarse aggregate quantity less than 50% of its dry rodded bulk density (typical volume ratio of 32%); for the well-graded and well shaped aggregate, this value could be increased to 60% (Okamura and Ozawa, 1995).On the other hand, the critical coarse aggregate volume ratio is less than 35% (Byun et al., 1998).

2.5.4 Mixing water

Water hasan outstanding role on the characteristics ofSCCboth fresh and hardened properties. Water decreases the plastic viscosity. Concrete has atendency to segregation if only water is added to increase the fillingability. For this reason , SCC could not have been produced without usingsuperplasticisers.

The moisture content of the aggregate has a significant influence on free water content. The moisture variation in sand from 3 ~ 4% led to the W / C ratiovariationof ± 0.1 (Pearson, 2000). Therefore, it is important to correctly estimate moisture content of the aggregate.Testing SCC projects suggested that the moisture content of the aggregates should be more than the level of SSD (Aarre and Domone, 2004).

Water content is another important factor to maintain the consistence retention besides superplasticiser types; That is, the higher the W/C ratio , the the consistence loss for the same initial consistence (Felekoglu and Arikahya, 2008).

2.5.5 Admixtures

There are manyadmixtures that have been stated as used in SCC,but high range water reducing admixturesand super plasticizersare an essentialconstituent of SCC to provide the necessary workability. Viscosity modifying admixtures (VMA)may also be used to help decrease segregation and sensitivity of the mix due to variations in other constituents, specifically to moisture content. Other admixtures including air entraining admixture, retarding and acceleratingmay be used in the similar way as in NVC.Select of admixture for optimum performance can be effected by the chemical and physical characteristics of the binders. Factors such ascarbon content, fineness, carbon content,alkalis and C_3A may have an effect(EFNARC, 2005).

2.6. Properties and performance of self-compacting concrete

2.6.1 Fresh properties of self-compacting concrete

Passing ability, filling ability, and segregation resistance are three fundamentals fresh properties of SCC (Testing-SCC, 2005; The Concrete Society and BRE, 2005). Passing ability is the feature of SCC to flow through and around complication's instance reinforcement and narrow spaces without blocking. Filling ability is the typical of SCC to flow below its own weight and to completely fill the formwork. SCC presented as a homogenous type of concrete after placing and transporting, due to its feature of segregation resistance. It is passing ability that differentiates SCC from another high consistence concrete. Additionally, strength besides consistence is other two important properties in utilization of SCC (Domone, 2000).

2.6.2 Hardened properties of self-compacting concrete

Important engineering properties such as strength, dimensional changes and durability mostly depend on the pore system, such as the total surface area, the total pore volume, the pore size distribution and thepore connectivity (Neville,1996).Concrete is a complex system with a wide range of pore sizes and is a structure which changes with time. Many papers have been published concerning all aspects of the hardened properties of SCC, often compared with conventialconcrete.

2.6.3. Hydration

The similar hydration mechanism governsSCC as that of NVC (RILEM TC 174 SCC, 2000).However, a high content of admixtures and bindermaterials may exert some influence on the hydrationdevelopment. For example, incorporation of limestone powder in the SCC led to a shorter induction period, and an increase in hydrationreaction act on the appearance of the peak of the third hydration (Poppe and Schutter, 2005).Fine powder particles acted like heterogeneous nucliation sites to accelarate hydration (Kadri and Duval, 2002). The setting time ofSCC wasreported to be twice as long as that of NVC dueto the superplasticiser and flyash used (Byun et al., 1998).

2.6.4 Compressive strength

SCC with asimilarwater to cement or water to binder ratio has approximatelty compressive strength and the strength developmentsimilar to NVC, and not significantly changed. The development of strength of SCC and NVC over aperiod of time is also similar (Dehn et al., 2000; Domone, 2007; Gibbs and Zhu, 1999; Holschemacher and Klug, 2002; Klug and Holschemacher, 2003; Sonebi and Bartos,2000).

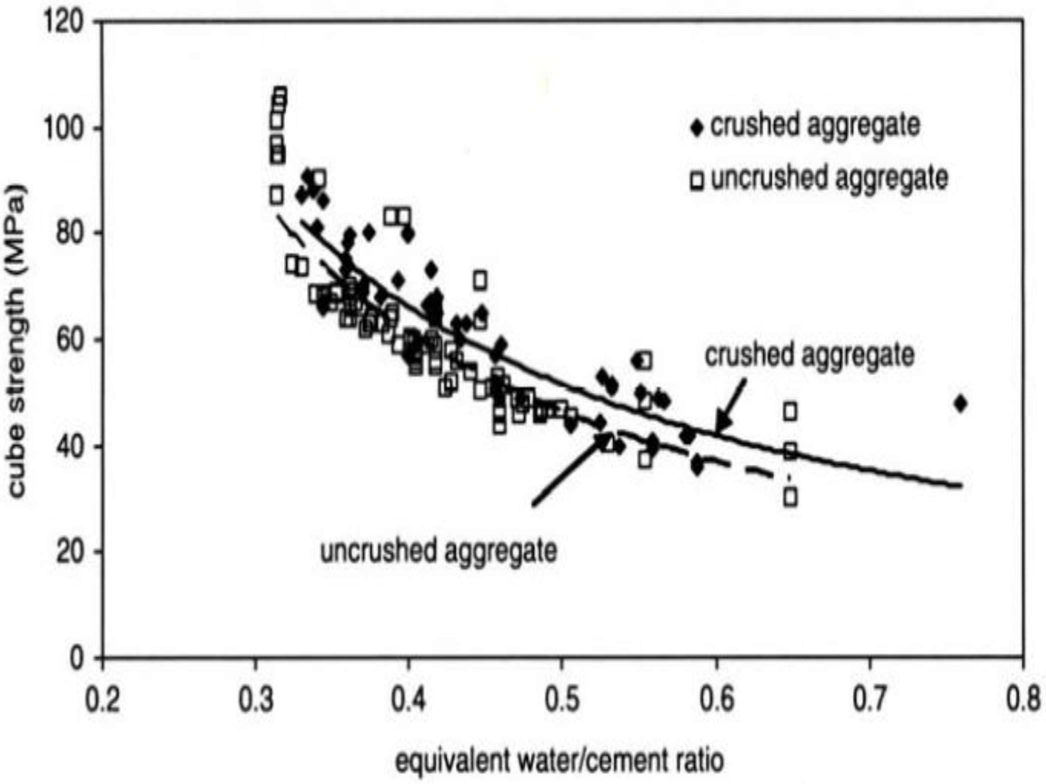

Figure 2.4The relationship between the compressive strength and the water to cement ratio (Domone, 2007)

There is a good relationship between compressive cube strengths and the equivalent water to cement ratio of SCC shown in Figure 2.4 (Domone, 2007). The difference in strength between SCC with crushed and uncrushed aggregate is 4 MPa which is half of the typical value (8MPa) assumed for NVC. The reasons given by Domone are the more regular matrix and the less coarse aggregate used. The influence of the difference between aggregates on SCC is not therefore as decisively significant as with NVC. The compressive strength of SCC at 28 days varied from 20 to 100 MPa depending on W/b ratio and binder composition (Domone, 2006b), which shows SCC could be used in many conditions.

2.6.5 Tensile strength

Where the W/P ratios are similar, the splitting tensile strength of SCC was greater than that of NVC (Holschemacher and Klug, 2002; Zhu et al., 2004); the tensile to compressive strength ratio of SCC was 10~30% greater than that of NVC (Gibbs and

Zhu, 1999; Gram and Pentti, 1999). This probably outcomes from the better microstructure of SCC.

2.6.6 Static modulus of elasticity

The modulus of elasticity (E-value, the ratio between stress and strain), is used in the calculation of elastic deflection, whichis controlling a parameter in slab design, and of prestressed or post tensioned elements.

Since the elastic modulus of concrete be influenced by the Young's moduliof the constituents and their volume ratio. It decreases with lower aggregatecontents, or with higher cement contents or higher porosity.

It is known that the coarse aggregate content of SCC is less than NVC, the elastic modulusof SCC might be estimated to be lower.This was established by (Dehn et al., 2000; Holschemacher and Klug, 2002) analysed their database and found thatthe elastic modulus of SCC could be 20% lower than that of NVC made of thesame aggregate with the same strength.

2.6.7 Bond properties

Reinforced concrete is based on an effective bond between concrete and the reinforcing bars. The concrete bond strength should be adequate to prevent bond failure. The effectiveness of bond is influinced by the position of the embedded bars and the quality of concrete as cast. An adequate concrete cover is required in order to properly transfer bond stresses between steel and concrete.

Poor bond often results from bleeding or segregation of the concrete. Waterand air rise and are trapped under the bars which lead to an irregular bondstrength along the bars, which is called the top bar effect. Bond strength is, thushigher in the lower parts of a concrete element and less at higher levels.

Because of the better homogeneity, the top bar effect was less distinctive inSCC (Domone, 2007; Holschemacher and Klug, 2002) the bond to steel ofSCC was similar to (de Almeida Filho FM et al., 2005) or better than that of NVC(Chan et al., 2003; Collepardi et al., 2005; Dehn et al., 2000; Domone, 2007).The bond strength of SCC was 10~40% higher than that of NVC with thesame strength grade 35 and 60 MPa for a bar diameter of 12 and 20 mm (Zhu et al., 2004).

2.6.8 Shrinkage and creep

Change in volume, e.g. shrinkage, is important for concrete because it producestensile stress inside the concrete leading to adverse cracks which makes itpossible for gas, water and harmful chemicals to penetrate into the concrete andcause further durability problems. Shrinkage was important for prestressedconcrete because it relaxed the prestressing force, thus reducing structuralcapacity (Atis, 2003).

Since shrinkage is a time-dependent deformation, including autogenous and dryingshrinkage. Autogenous shrinkage occursduring setting and is caused by the internal consumption of water during hydration. The volume of the hydration products is not more than the original volume of unhydrated cement and water. It depends on the W/C ratio andthe age of the concrete, and increased if the W/C ratio is reduced; it wasapparent when the W/C ratio is less than 0.38 (Persson, 1997). Drying shrinkageresults from the loss of water from the cement paste into the atmosphere. Waterheld by capillary tension is one of the important factors influencing the dryingshrinkage.

Since SCC contains higher paste, powder and superplasticiser this may contribute to higher shrinkage and creep than in NVC.The dryingshrinkage of SCC was found to be 10~50% higher than that of NVC (Holschemacher and Klug, 2002; Suksawang et al., 2006), and lower shrinkage of SCC was stated (Bouzoubaa and Lachemi, 2001; Sonebi and Bartos, 2000).Use oflimestone powder in SCC was found to reduce shrinkage (Bui and Montgomery, 1999a; Chopin et al., 2003).Other studies reported that the amount of shrinkageof SCC did not change from that of NVC when the compressive strength was thesame (Persson, 2001; Poppe and Schutter, 2003). The above contradictions maybe the outcome of different experimental procedures, specimen sizes and materialproperties.

Creep is defined as the gradual increase in strain for a constant applied stress. Itis also a time-dependent deformation. Creep takes place in the cement paste andis influenced by porosity which isrelates to the W/C ratio.During hydration, the porosity of the cement paste reduces and so for a given concrete, creep decreases as the strength increases. The type of cement is important if the age of loading is fixed.As the aggregates restrain the creep of the cement paste, the higher the volume of the aggregate and the higher the E-value of the aggregate, the lower the creep will be.

Due to the higher volume of cement paste, the creep coefficient for SCC may be expected to be higher than for NVC of equal strength.However, no general report about the creep of SCC can begiven due to the lack of and contradictory nature of existing data (Holschemacher and Klug, 2002).

2.6.9Durability

Durability is a general investigation of the service life and the performance of concrete in an aggressive environment. Physical damage to concrete contains wetting/drying, freeze/thaw or heating/cooling cycles. Chemical damage contains of sulphate attack, acid attack, chloride attack and alkali-silica reaction (ASR) in which water acts as a carrier. All are greatly influinced by the resistance of the cover layer to transport mechanisms such as permeation, absorption and diffusion of gas and liquid. Thus oxygen permeability, water sorptivity and chloride conductivity have often been defined as three durability indexes due to the simple and inexpensive test methods (Alexander and Magee, 1999).

A brief summary of water transport in concrete and other durability parts ofSCC are verified as follows:

Sorptivity is the water movement driven by capillary action in short-termexposure in partially dry concrete. The capillary force exertedby the pore structure causing fluids to be drawn intothe body of the material is known as sorptivity.The pore structure of thepaste and the interfacial zone has a great effect on sorptivity. The interfacialzone is porous but it is the hardened paste, the only continuous phase inconcrete, that controls the ingress and transportation of water (Sabir et al., 1998). Sorptivity of SCC was only 30~40% of those of NVC with the same strengthgrade C40 (Zhu and Bartos, 2003).

Diffusion is the water movement driven by a concentration gradient in longtermexposure. For example, the durability of concrete in the sea is mainlydetermined by the diffusivity of the chloride solution entering and movingthrough the matrix. Chloride diffusivity depends on the tortuosity of the poresas an alternative of the total porosity. As theFA particles made concrete dense,concrete incorporating FA was stated to have a lower chloride diffusivity(Zhu and Bartos, 2003). On the other hand, Tang et al (1999) testified a higherchloride diffusivity than NVC because of the poor dispersion of powders. It isinteresting to note that the diffusivity of SCC with VMA is greater than NVC and powder-typeSCC (Zhu and Bartos, 2003). This approves that the powders used in SCC improve packing density leading to a denser structure. Diffusionand capillary action are the principal mechanisms of ingress of water.

Capillary porosity has a significant effect on hardened properties and isuseful for predicting the durability (Yaman et al., 2002). The capillary transportespecially near concrete surface is the dominant invasion mechanism. Anincrease in the porosity of the concrete cover leads to more water and additionaldissolved chemical flowing through the surface, and thus, more durabilityproblems. The relationships between water absorption and some durability suchas the resistance of concrete to carbonation and chloride (De Schutter andAudenaert, 2004),freezing/thawing and wet/dry cycles (Martys andFerraris, 1997) were examined.

Permeability is a process in which water is transported under a hydrostaticpressure differential. The main effects on permeation consist of the pastevolume, the pore structure and the interfacial zone between the mortar andaggregates. The overall porosity of SCC was lower than that of NVC of same strength because of the larger powder content, lower W/P ratio andbetter microstructure (Tragardh, 1999; Zhu et al., 2004; Zhu and Bartos,2003). Zhu and Bartos stated that the oxygen permeability for SCC was only30~40% of that of NVC with the equivalent strength grade C40.

Other researches on durability between SCC and NVC contain:

- SCC with limestone powder showed better internal frost resistance than NVC with the equivalent W/C ratio and air content but there was little difference between SCC and NVC for salt (NaCl) and sulphate resistance (Persson, 2003).
- SCC showed lower freeze-thaw resistance than NVC (Zhu and Bartos, 2003).
- Few fire investigations have been done on SCC. Cylinders with different mix proportions of strength up to 104 MPa of SCC were tested; slight spalling happened for SCC; the degree of spalling also depended on the type of additions used (Vanwalleghem et al., 2003). SCC was more prone to spalling than NVC

with the same strength grade (Bostrom, 2003; Noumowe et al., 2006). This may be attributed to the denser microstructure of SCC.

2.7 Silica fume

SF is considered the moderately short, and the first documented testing of the SF in the Portland cement constructed the concretes mainly was in the year 1952 as well as it was not used up until the early of 1970s, generally that concretes is containing the SF came into the constant uniform partial use. The key weakness is in determination of the exceptional characteristics of the SF then it is possible there was an absence of the SF to the experimentation. In general, the early researches use the exclusive addition which named Fumed silica; the silicon's burning is tetrachloride, which causes to make the colloidal form of silica in the furnaces of the hydrogen-oxygen. On the other perspective, the SF is considered as very adequate pozzolanic or a consequence material, self-possessed of the frequently formless (amorphous) silica formed by the furnaces of the electric arc all through manufacture of the essential silicon or the alloys of the Ferro silicon. In the past, the late 1960‟s in the Europe as well as the mid of the 1970‟s in US; silica fume merely departed up the mound as smoke expressed into the mesosphere, as shown in Figure 2.5 (Yajun and Cahyadi, 2003).

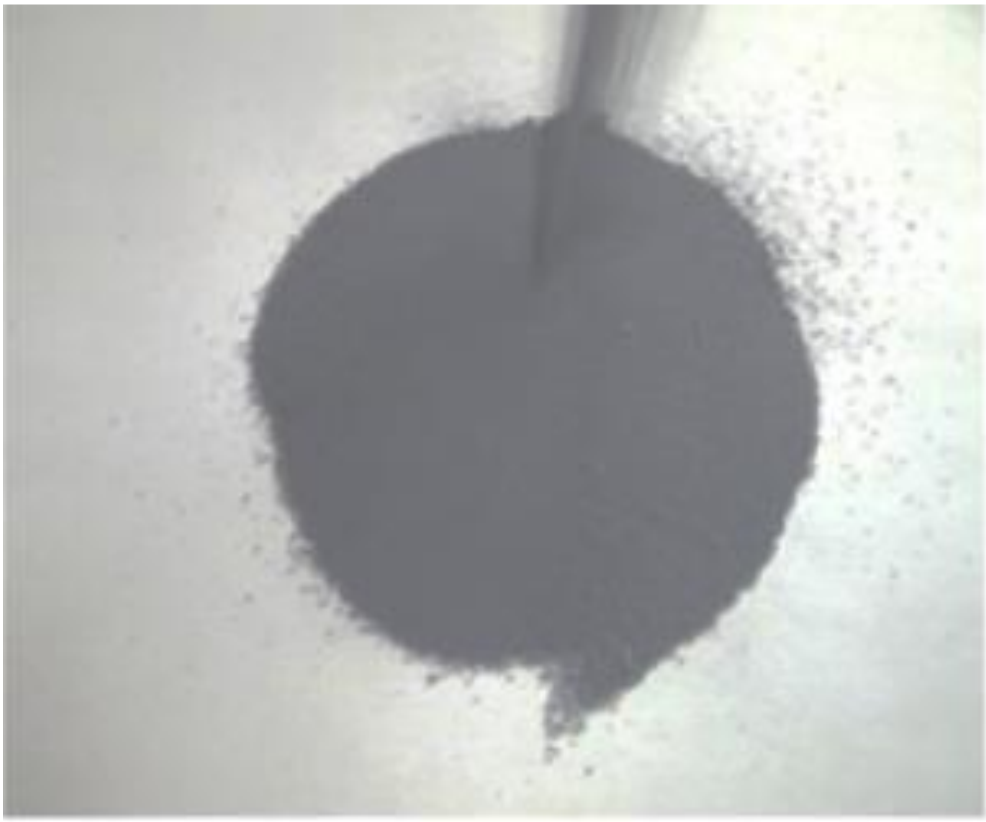

Figure 2.5Photographic view of silica fume (Yajun and Cahyadi, 2003)

2.8Waste coarse rubber aggregate (WRA)

2.8.1 Back ground

Concrete is a combination of cement, aggregates and water. Aggregates constitute about 70% by weight of the concrete. There is a great demand for natural aggregates as the construction actions are increasing every day. As the natural resources are decreasing, some alternate materials that will help the purpose of the natural aggregates should be presented. (Blessen et al., 2013).

The modern life style along with the new technologies producedmore waste materials productions for which the disposing problemtake place. Majority of the waste materials are non-disposal and remainfor along periods of time in the environment. Thesenon-recyclable wastes along with population developmenthave caused the environmental disaster all around the world. Many ofthem are bloated in the dump place or they are outpoured in thewastebasketsillegally (Rahmani et al., 2013).

The use of rubber wastes in the construction engineering is now well-developed as it helps in improving the sustainability in two ways. First, reuse of the materials which otherwise will make problems to the environment and will be occupying limited land resource. Second, it reduces the degradation of land and the environment as a result of relatively less digging. ‘‘Recycling’’ is an fundamental practice now as it protects the planet’s resources (Terro MJ, 2007).

Widodo and Slamet (2012)investigated the influences of PP fiber on some mechanicalcharacteristics of SCC.In thierinvestigation, concrete mixures were prepared with PP fiber of four volume fracions 0%, 0.05%, 0.10%, and 0.15%.After 28 days of curing specimens, concrete samples tests shows that PP fiber addition until 0.10% of volume fraction tend toimprovethe compressive strengthtensile strength andresistance to impact loads of hardened SCC. Moreover, theyrecommended that PP fibers acceptable to be used in SCC mixes up to 0.10% by concrete volume.

2.8.2 Characteristics of waste coarse rubber aggregate(WRA)

Waste rubber aggregate named polypropyline plastic granules is a plastic polymer, of the chemical designation C3H6. It is used in various different locations, both in industry and in consumer goods. It can be used both as a structural plastic and as a fiber. PP is often used for food containers, mainly those that need to be dishwasher safe. The melting point of PP is very high compared to many other plastics, at 320°F (160°C), which means that the hot water used when washing dishes will not cause PP dishware to warp. This differences with polyethylene, another popular plastic for containers, which has a much lower melting point. PP is also very easy to add colors to, and is often used as a fiber in carpet tiles which needs to be strong and durable, for instance the carpet one finds around swimming pools or paving miniature golf courses. Unlike nylon polyamide, which is also often used as a fiber for rugged carpeting, polypropylene doesn't soak up water, making it perfect for uses where it will be constantly subject to moisture (www.wikipedia.com).

Polypropylene Granules show good resistance against bases, chemical solvents and acids. This PP granule is respected for its qualitative aspects like stiffness, thermal stability, high tensile strength, low melting point, dimensional stability and purity. Polypropylene Granules are used in making bottles, containers, Medicine bottles, automobile battery casings, loudspeakers and textile products. Apart from this, these granules are also used for packaging purposes.

Modern plastics demonstrated to be one of the most revolutionarymaterials established in the twentieth century, with variousapplications in several industries, such as packaging, buildingand construction, automotive, electrical and electronics. Since theirdevelopment in the 1930s, the consumption of plastics has beenincreasing consistently and significantly. Between 1950 and2011, the annual world production of plastics increased from 1.7to 280 million tons (Europe, P. 2010).

The reuse ofsolid plastic wastes to produce other materials, namely concrete,stands out as one of the most economical and sustainable alternativesto dispose of this type of waste(Saikia et al., 2014).

2.8.3Effect of waste rubber aggregates on mechanical properties of SCC

Recently, most researchers have shown great interest in the use of rubber particles in concrete production. In all their studies, it was remarked that the size, surface texture and volume of the rubber particles havea great effect in the mechanical characteristics of the modified concrete.

Topcu (1995) substituted fine aggregate by rubber fine grains and coarse aggregate by coarse rubber crumbs. The 6-month cylindrical compressive strength of the initial concrete was 33.67 MPa which decreased to 20.23, 11.06 and 7.16 MPa by adding 15, 30 and 45% rubber fine grains, and 15.75, 10.82 and 7.72 MPa by adding the same quantity of coarse rubber crumbs. These demonstrations that coarse rubber grains show more negative effect on compressive strength than fine rubber particles. They also stated that the samples had significant load bearing capability after rupture and offered significant displacements without complete separation. These displacements and deformations were reversible after load releasing.

Eldin and Senouci (1993) also substituted coarse and fine aggregate of the concrete by rubber crumbs and rubber powder, respectively. They pretreated the old rubbers by water. By 100% substitution of coarse aggregate by rubber crumbs, the maximum compressive strength reduction reached 85%. But the effect of sand replacement by fine rubber grains resulted in 65% strength reduction.

The strength properties and modulus of elasticity of concrete including different types of plastic aggregates are always lower than those of a reference concrete having normal density natural aggregate only, and they further reduce with increasing plastic aggregates content in concrete (Siddique et al., 2008). However, it has been requested that the incorporation of shredded PET-aggregate up to a certain level does not effect the compressive and flexural strengths of cement mortar (Marzouk et al., 2007).

Due to (Grdic et al., 2010) when coarse recycled aggregate of good quality is used, the total substitution of the natural coarse aggregate by recycled aggregate from demolition of concrete structures has a minimal influence on the compressive and tensile strength reduction. The authors found a reduction of 9% for compressive strength and 13% for tensile strength, at 28 days. Regardless of the relatively high water absorption of coarse recycled aggregates, they also noticed a minimal increasing of recycled aggregates SCC water absorption of 0.4% when compared with control concrete.

Olivares et al., (2007) represent the results of fatigue behavior of rubberized concrete prismatic specimens. They have used %0, %3.5 and %5 volumetric portions of rubbers. The prismatic samples were exposed to natural weathering for one year, and then three point bending fatigue tests were achieved. As a result, it is obtained that the possibility of using rubberized cement based composite material as a rigid pavement for roads on elastic subgrade.

Kaloush et al., (2006) reported that the higher rubber contentmixes had a lower flexural strength than plainconcrete. On the other hand the rubberized concrete mixes hadmore ductility and equivalent toughness values tothe plain concrete. Rubberized concretes are moreresistant to thermal changes and in all failure tests,the rubberized concrete specimens stayed intact indicatingthat the rubber particles may be absorbingforces acting upon it.

Güneyisi et al., (2004) have used silica fume for improving thebond performance of rubberized concretes. Crumbrubbers and tire chips were replaced as two types of tirerubber in the mixtures. They have stated that therewas a large reduction in the strength and elasticmodulus values with the increase in rubber content.However, the silica fume enhanced the bond performanceof matrix .

2.8.4 Effect of waste rubber aggregates on durability properties of SCC

In the literate, durability of rubberized concretes has not foundsufficient consideration. The addition of rubbers to SCC could be affect the durability properties of self compacting concrete.

Savas et al., (1996) worked on the rapid freeze–thaw resistance of the concrete including different amounts of ground rubber aggregates. They reported that the rubberized concretehad lower performance against freezing and thawing damage.

Gesoglu and Guneyisi (2007) examined that the use of rubber particles significantly aggravated the chloride ion penetration through concretesuch that there was a regular increase in depth of chloridepenetration with the increase in rubber content for concretes withand without SF, specifically at high w/cm ratio. As the rubbercontent increased from 0% to 25% by total aggregate volume,the chloride permeability of the rubberized concrete with andwithout SF was about 6–40% at 0.60 w/cm ratio and about27–59% at 0.40 w/cm ratio larger than that of the controlled concrete.

Benazzouk et al., (2004) investigated the effect ofrubber aggregates on the durability factors of cement–rubber compositesin terms of capillary absorption, hydraulic diffusivity, andair permeability measurements. They determined that the presenceof rubber particles decreases sorptivity and hydraulic diffusivity byreducing water absorption. Also, air permeability was significantly decreased due to the presence of these additives. The cellularcharacter of rubber further improves behavior when in contactwith fluid.

Gesoğlu and Güneyisi (2011) Alsoinvestigated the permeability properties of SCRCs with and without FA. At a water–cementitious material (w/cm)ratio of 0.35, the self-compacting concretes (SCCs) were produced by substituting the fine aggregate withfour designated crump rubber contents of 0%, 5%, 15%, and 25% by fine aggregate volume. Moreover,the SCCs with FA were produced by partial replacement of cement with FA at different amountsof 20% to 60%. They determined that using the crumb rubber aggravated all of the measuredproperties of SCRCs. On the other hand, with the combineduse of the crump rubber and FA, the concretes had better resistance to the chloride ion permeability,water sorptivity, and water absorption.

Yung et al., (2013) used waste tire rubber as a recycled material and substituted part of the fine aggregate by wastetire rubber powder sieved through #30 and #50 sieves to produce SCRC. Part of the fine aggregate was substituted with waste tire rubber powder that had been passedthrough sieves at volume ratios of 5%, 10%, 15% and 20%. They showed that when 5% waste tire rubber powder that had been passed through a #50 sievewas added, the 91 day compressive strength was greater than the control group by 10%. Additionally, theshrinkage was higher with an increase in the quantity of waste rubber, and reached its maximum at 20%.The ultrasonic pulse velocity reduced when additional powder was added, and the 56 day electrical resistanceexceeded 20 kΩ-cm and was increased with the addition of more powder.

Gavela et al., (2013) Used thermoplastic wastes in concrete, The influence of the polymers on the reinforcement corrosion of concretes including them asaggregates has been studied.Two types of thermoplastic waste were replaced, high density polyethyleneand polypropylene. Measurements were carried out to investigate whether the corrosion behaviourof the reinforcement bars has changed due to the replacement of the conventional aggregates by the polymers, upto 240 days of immersion of specimens in 3.5 wt% NaCl solution. Results showed that the replacement of conventional aggregates by the two polymers investigated does not worsen reinforcement bars corrosion behaviour.

CHAPTER 3

EXPERIMENTAL PROGRAM

3.1 Materials

3.1.1 Cement and Fly ash

In this currentstudy, ordinary Portland cement CEM I 42.5R was used for producingall concrete mixtures. Type F FA, supplied from Çatalağzı Thermal Power Plant, Zonguldak in Turkey, was utilizedas a secondary binder material at a 20% substitution level by weight of cement in producing SCRCs. Physical and chemical properties of cement and FA are given in Table 3.1.

3.1.2 Silica fume

SF was used to improve hardened properties of SCRC as a ternary cementitious blends with FA and cement.SF was replaced at %10 replacement level by weight of cement in producing SCRCs.Chemical and physicalproperties of SF are given in Table 3.1.

3.1.3 High Range Water Reducing Admixture

High Range Water Reducing Admixture (HRWRA) with a specific gravity of 1.07 was used to obtain the required workability in SCRCs. The properties of HRWRA are presented in Table 3.2.

3.1.4 Aggregates

3.1.4.1 Waste coarse rubber aggregate

In this study,WRA named polypropyline plastic granules with a specific gravity of 0.95 and the particle sizedistributionbetween (4-8mm) as a medium aggregate replacement was used to produce SCRC mixtures(Figure 3.1).

Figure 3.1Photographic view WRA used in the production of SCRC

3.1.4.2 Normal Aggregates

Natural fine (NFA) and Crushed Limestone coarse aggregates (NCA) were used together with WRA in order to produce SCRC. In this study, medium Crushed coarse aggregates were replaced by WRA to produce SCRC mixtures. For natural fine aggregate, a natural river sands with a maximum size of 4 mm was used. Two Sizes of Crushed Limestone coarse aggregate (medium and coarse) having a maximum size of

(4-8)mm and (4-16)mm respectively were used. The particle size distribution and physical properties of natural aggregates are shown in Table 3.3.

Table 3.1Chemical compositions and physical properties of Portland cement, FA and SF.

Analysis Report (%)	Cement	Fly ash	Silica fume
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
Blaine fineness(m^2/kg)	328	379	21080

Table 3.2Properties of High Range Water Reducing Admixture (HRWRA)

Properties	High range water reducer admixture
Name	Glenium 51
Color tone	Dark brown
State	Liquid
Specific gravity	1.07
Chemical description	Polycarboxylic-ether

Table 3.3sieve analysis and physical properties of natural aggregates

Sieve size (mm)	Natural sand	Crushed coarse aggregate	Crushed medium aggregate
16	100	100	100
8	100	5.35	79.25
4	100	0.25	3.25
2	68.3	0	0.4
1	44.6	0	0
0.5	24.8	0	0
0.25	8.7	0	0
Specific gravity	2.89	2.64	2.66

3.2 Self Compacting Rubberized Concrete Mix Properties

Two different series of self-compacting rubberized concrete (SCRC) mixtureswere designed with a constant water–cementitious material (w/cm) ratio of 0.32 and total cementitious materials content of 550 kg/m3. The first group of mixtureswasincorporated binary cementitious blends of 20% FA with 80% Portland cement. However, the second series of the mixtures incorporated ternary cementitious blends of 20% FA with 10% SF and70% Portland cement. To develop the RSCCs, medium aggregate was substituted by the WRA at five designated contents of 0%, 10%, 20%, 30% and 40% by volume in both series of concretes. Therefore, 10 different SCRCmixtures were designed as given in Table 3.4 in details. All of the concrete mixtureswere cast to give a slump flow diameter of 70 ± 5 cm which was tried to achieve by using the superplastisizer at varying amounts.

Table 3.4Concrete mix proportions in kg/m^3

Code number	w/b	cement	FA	SF	water	Coarse aggregate			sand	HRWRA
						NCA		WRA	NFA	
						4-8mm	4-16mm	4-8mm	0-4mm	
SF0R0	0.32	440	110	0	176	391.8	391.8	0	783.5	7.4
SF0R10	0.32	440	110	0	176	352.7	391.8	14	783.7	7.4
SF0R20	0.32	440	110	0	176	313.6	391.8	28	783.9	7.1
SF0R30	0.32	440	110	0	176	274.5	391.8	42	784.1	6.9
SF0R40	0.32	440	110	0	176	235.3	391.8	56	784.5	6.6
SF10R0	0.32	385	110	55	176	387	387	0	774.1	8.8
SF10R10	0.32	385	110	55	176	348.4	387	13.8	774.3	8.7
SF10R20	0.32	385	110	55	176	309.8	387	27.7	774.5	8.5
SF10R30	0.32	385	110	55	176	271.2	387	41.5	774.7	8.5
SF10R40	0.32	385	110	55	176	232.5	387	55.4	775	8.4

* FA: Fly ash; SF: Silica fume; HRWRA: High Range Water Reducing Admixture; WRA: Waste rubber aggregate

* NCA: Natural coarse aggregate: NFA: Natural fine aggregate

3.3 Concrete Mixing and Casting

The mixing sequence and duration are very important in the SCC production. For this reason, mixing and batching procedure recommended by Khayat et al., (2000) was followed in this study in order to obtain the same homogeneity and uniformity in all Mixtures. Regarding to this procedure, the fine, rubber and coarse aggregates were poured in a power-driven revolving pan mixer and allowed to mix homogeneously for 30 seconds. After that about half of the mixing water was added into the mixer and it was allowed to proceed the mixing for one more minute. The aggregates, then, were left to absorb the water for 1 minute. Afterwards, the powder materials (cement and/or fly ash and/or silica fume) were added to the wetted aggregate mixture for mixing another minute. After HRWRA with remaining water was poured into the mixer, the concrete was mixed for 3 min and then left to rest for a 2 min. Eventually, the concrete was mixed for additional 2 min to complete the production. The slump flow diameter of SCRCs was designed to be in the range of 700±50 mm to provide EFNARC (2005) limitation. So, test batches were cast for each type of mixture by using HRWRA at varying amounts to obtain the target mentioned slump flow diameter.

After the mixing procedure had completed, fresh concrete mixtures were tested for workability. The compressive strength, splitting tensile strength,modulus of elasticity, net flexural strength, fracture test, water sorptivity, rapid chloride permeability and gas permeability of SCRCs were also determined in the hardened state. All of the specimens were cast without any vibration or compaction.

Specimens were cast from each mixture consisting of the following:

- Six 150 mm cubes for the compressive strength evaluation at 28 and 90 days;
- Two 100x200 mm cylinders for splitting tensile strength at 90 days;
- Two 150x300 mm cylinders for modulus of elasticity at 90 days;
- Two150x300 mm cylinder for gas permeability test at 28 and 90 days;
- Four 100x200 mm cylinders for rapid chloride permeability and sorptivity at 28 and 90 days;
- Three 100x100x500 mm prisms for determination of fracture energy and net flexural strength at 90 days;

Figure 3.2 presents the casting of self compacting rubberized concrete specimens. The specimenswere demoulded 24 h after casting and stored in water tank at23±2°C untilthe age of testing as shown in Figure 3.3.

Figure 3.2Casting of self-compacting rubberized concrete specimens

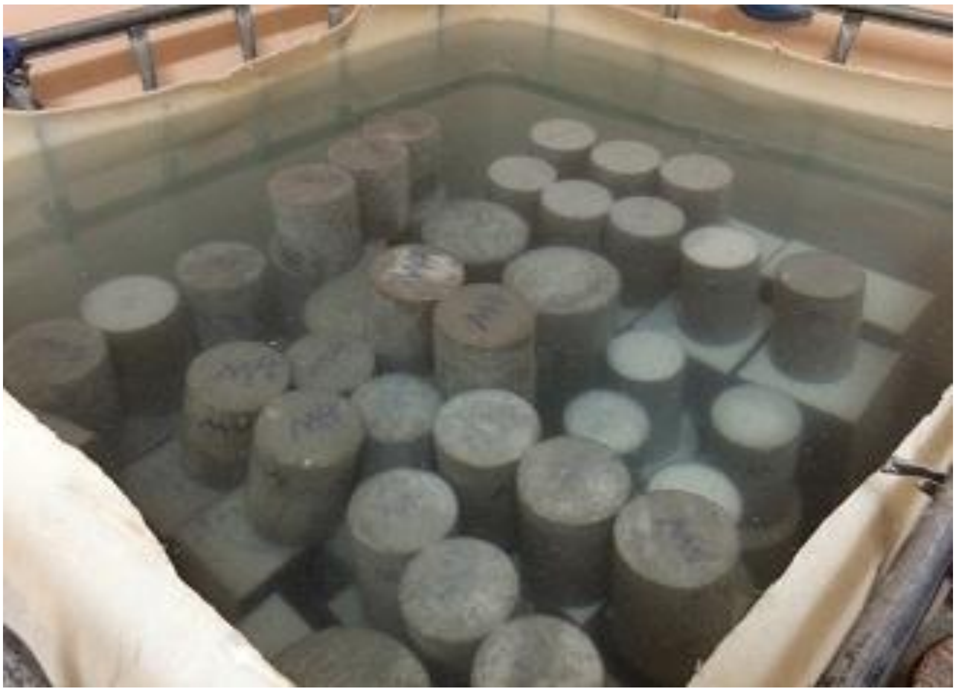

Figure3.3Curing of self-compacting rubberized concrete specimens

3.4 Tests for Mechanical Properties

3.4.1 Compressive Strength Test

For compressive strength measurement of SCRC, cubical specimens of 150 mm were tested with respect to ASTM C 39 (2012) by means of 3000 KN capacity testing machine. The test was conducted on three samples from each SCRC mix at 28 and 90 days. The compressive strength was measured by averaging the results from the three tested specimens at each age of testing.

3.4.2 Splitting Tensile Strength Test

According to ASTM 496 (2011), splitting tensile strength of the concretes was determined by using the cylindrical samples of Ø100x200 mm at 90 days. The splitting tensile strength was obtained by averaging the results from the two tested cylindrical samples.although, the splitting tensile strength (f_{st}) in MPa will be calculated by Equation 3.1.

$$\mathbf{f_{st}} = \frac{\mathbf{2P}}{\boldsymbol{\pi}\,\mathbf{d\,L}} \quad (3.1)$$

Where P, d, L is the maximum load in N, diameter in mm, and length of the cylinder mold respectively.

3.4.3 Modulus of Elasticity Test

Cylinders with a dimension of Ø150x300 were tested for determining the static modulus of elasticity according to ASTM C469. Each of the specimens was fitted with a Compressometer Containing a dial gage capable of measuring deformation to 0.002mmAnd then loaded three times to 40% of the ultimate load of Companion Cylinder. The first set of reading of each Cylinder was discarded and the modulus was reported as the second setting of readings. The static modulus of elasticity was obtained by results from the two tested cylindrical samples as shown in Figure 3.4.

Figure3.4Concretespecimen setting for elastic modulus measurement according to dial gage cable.

3.4.4 Fracture Energy and net flexural strength

In order to calculate the fracture energy (GF) of SCRCs, the test was carried out according to RILEM 50-FMC (1985). The measurement of displacement was observed simultaneously via a linear variable displacement transducer (LVDT) at midpoint of span. A testing machine (Instron 5590R) having a highest performance of 250 kN for applying to load was used (Figure 3.5). The details of the testing machine and specimen as well as placing LVDT are shown in Figure 3.6.

The beams having a 500 mm length and cross-section of 100x100 mm were cast to calculate fracture energy test. The opening notch was doneby reducing the effective cross section to 60x100 mm via a sawing so as to locate coarser aggregates in more denseness. Thus, the notch versus depth ratio (a/D) of beams was 0.4. However, the distance between supports of the specimens was 400 mm.

After obtaining the curve of load versus deflection at the midpoint of span (δ) for each beam, the area under this load versus displacement at midpoint of span (Wo), G_F was calculated via the following formulation (Equation 3.2) by RILEM 50-FMC (1985).

$$\mathbf{G_F}=\frac{\mathbf{W_o+mg\,\frac{S}{U}\delta s}}{\mathbf{B(W\text{-}a)}}\quad(3.2)$$

In this formula, the width, depth, notch depth, span, length, mass, specified deflection of the beam and gravitational acceleration are presented as B, W, a, S, U, m, δs, and g, respectively. For each SCRC, three specimens were tested at 90-day.For SCRCs determination of fracture energy is dependent on the area under the whole load versus deflection at midpoint of span curve as much as a limited displacement 1.5 mm displacement chosen as cut-off point. The beam specimens were loaded at a constant rate of 0.02 mm/min.

The notched specimens were used to calculate the net flexural strength ($f_{\text{flex.}}$) by the given formulation (Equation 3.3) assuming no notch sensitivity, where Pmax is the ultimate load.

$$f_{flex}=\frac{\mathbf{3P_{max}S}}{\mathbf{2B(W\text{-}a)^2}}\quad(3.3)$$

By the following expression, the brittleness of materials can be determined in terms of characteristic length (Hillerborg, 1985):

$$\mathbf{l_{ch}}=\frac{\mathbf{E\ G_F}}{f_{\mathbf{st}}^2} \quad (3.4)$$

Where, fst, E, and G_F are the splitting tensile strength, static elastic modulus, and fracture energy, respectively. In this study, splitting tensile strength was used instead of direct tensile strength.

Figure3.5Photographic view of universal testing devices and three point flexural testing fixture

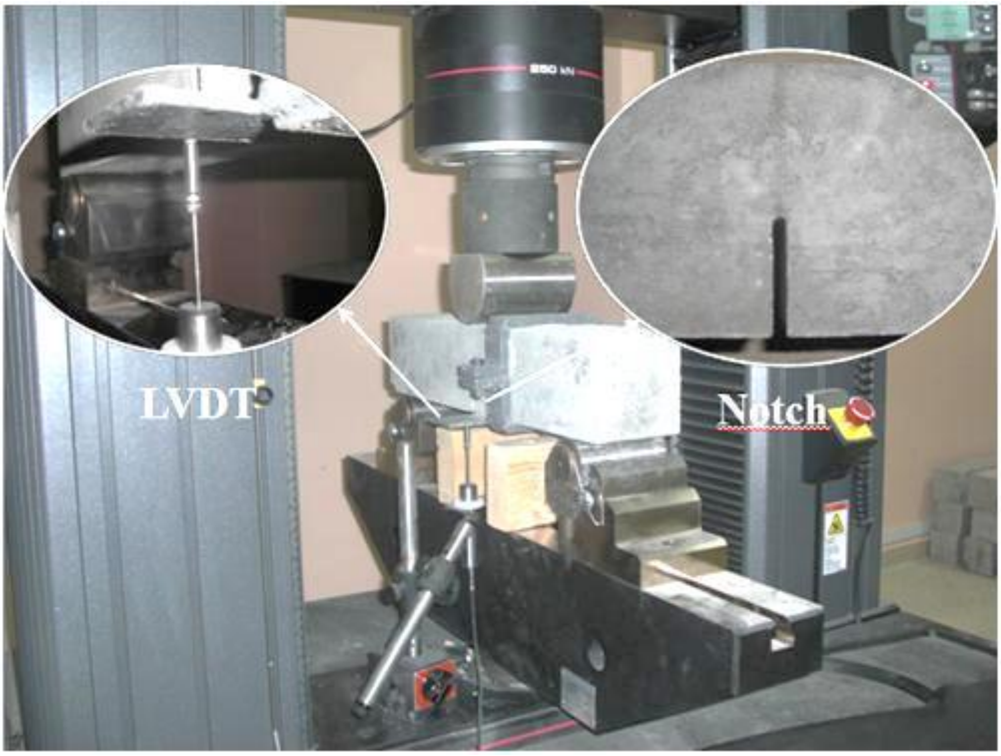

Figure 3.6 Photographic view of notched beam specimen

3.5 Determination of the Durability Performance of SCCs

3.5.1 Water Sorptivity

The sorptivity measures the rate at wich water in drawn into the pores of concrete. For this, four test samples having a dimension of Ø100x65 mm cut from Ø100x200 mm cylinders were employed. The samples were dried in an oven at about 100±5^{o}Ctill they reached the constant weight, and then kept insealed container to cool in ambient temperature. After wards, the sides of the specimens were coated by silicone, the sorptivity test was conducted by placing the samples on glass rods in atray such that their bottom surface upto a hight of (3mm) is in contact with water. This process was considered to allow free water movement through the bottom surface. The total surface area of water in the tray should not be less than 10 times that of the specimens cross-sectional area (Razak et al., 2004). The samples were removed from the tray and weighted at different time intervals up to 1hr to estimate mass gain. The absorbed water volume was determined by dividing the mass gained by the nominal surface area of the sample and by the water density. Then, the square root of time versus these values was plotted and the sorptivityindex of concretes was calculated by the slope of the line of the best fit. Test setup was given in Figure 3.7. For each mixture, four specimens were tested for 28 and 90 days, and the average of them was stated, Consecutively, at various times such as, 0, 1, 4, 9, 16, 25, 36, 49 and 64 min.

3.5.2 Rapid Chloride Permeability

An experimental setup meeting the ASTM C 1202 (2012) was followed to determine the resistance of SCRCs against penetration of chloride ions as shown in Figure 3.8. Two specimens of Ø100x200mm were tried out at the same time for each SCRC at 28 and 90 days. For this, two 50 mm thick disc specimens were cut from the mid-section of each cylinder. Then, the discs were allowed to surface dry in air. In order to prevent evaporation of water from the saturated specimen, a rapid setting coating was applied onto the lateral surface of the specimens prior to a vacuum-saturation procedure for 2 hrs. Finally, the specimens were immersed in water in the curing room at 20^{o}C and 50% relative humidity for 18±2 hrs. Following this conditioning procedure, the disc specimens, whose one side got in touch with 0.30 N NaOH solution and the other side was in contact with 3% NaCl solution, were relocated in a test cell (Figures 3.8 and 3.9). A direct voltage of 60.0±0.1 V was enforced between the faces by the power supply. Due to this applied voltage the chloride ions in the NaCl solution, being negatively charged, were attracted by the opposite positive electrode (+) and they penetrate through the pores of saturated concrete. The data was measured at every 30 minutes to record the current passing through the specimens over a 6 hour period. After being completed the test, current (in amperes) versus time (in seconds) were drawn for each specimen. And the area under the curve was computed to acquire the charge passed (in coulombs). Five types from Hig to Negligible were categorized according to ASTM C1202 (2012) depending on total coulomb value as given in Table 3.5.

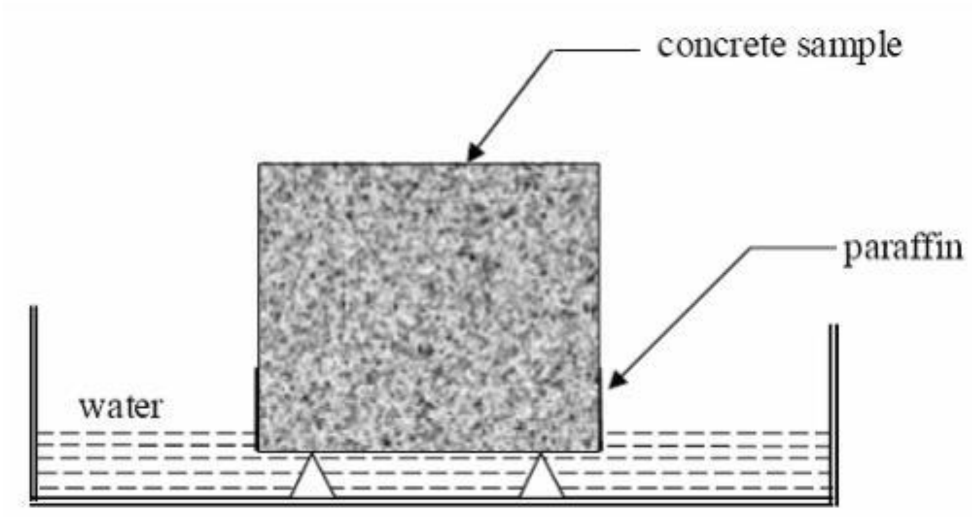

Figure 3.6Water sorptivity test set up

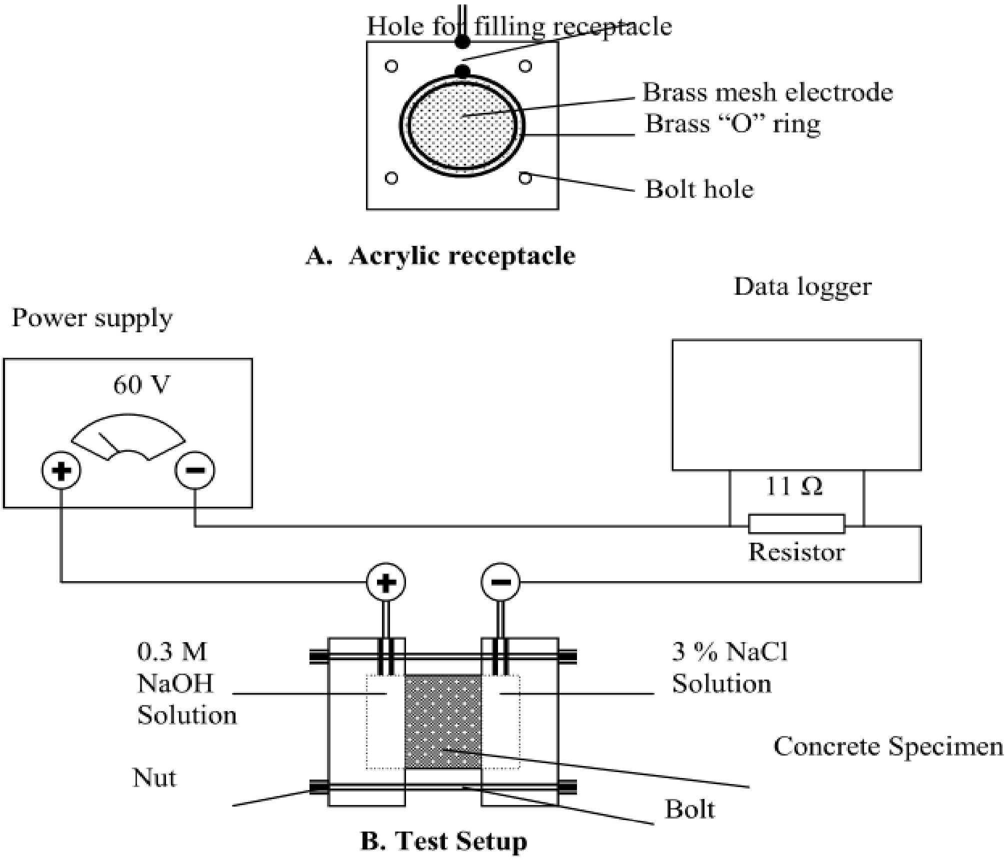

Figure3.7Diagramrepresentation of the test set up for RCPT

Table 3.5Interpretation of the test results obtained using RCPT test (ASTM C1202, 2012)

Charged Passed (Coulombs)	Chloride Permeability
>4000	High
2000-4000	Moderate
1000-2000	Low
100-1000	Very Low
<100	Negligible

Figure 3.8Photographic view of the RCPT test set up

3.5.3 Gas Permeability

A RILEM TC 116 (1999) procedure, the CEMBUREAU method was used for measuring the gas permeability coefficients of concretes. The gaspermeabilitywas determined on 50 mm height and 150 mm diameter disk specimens cut from the midpoint section of Ø150x300 mm cylinders. When the curing period of 28 and 90 days were ended, the samples dried at 50±5°C in oven to make sure each sample weight change was smaller than 1%. Then, they were saved in a sealed box till test began. At each testing age, two specimens were investigated and the average of them was recorded. The photographic view and the diagram layout of the apparatus as well as the detail of the testing cell are shown in Figures 3.10-3.12. The steps of the gas permeability test are as follows;

1. Measure the diameter of the test specimen in 4 positions (two perpendicular diameters in both top and bottom faces) with a precision of 0.1 mm. The diameter D is the mean value of the four readings. The thickness L of the testspecimen is determined in four positions equally distributed along the perimeter.
2. Place the test specimen in the cell and assemble the apparatus.
3. Build up a minimum lateral pressure of 7 bar (0.70 MPa) on the rubber tube.
4. Select 3 pressure stages: start with 1.5 bar (0.15 MPa) and increase to 2.0 (0.20 MPa) and then 3.0 bar (0.30 MPa) absolute gas pressure. Correct the input pressure of gas if necessary within 10 minutes.
5. Wait for 30 seconds before measuring the first flow.
6. Measure the flow at each pressure stage until it becomes constant, as follows:
    a. Moisten the capillary of the soap bubble flow meter 1 minute before creating the bubble for measurement.
    b. Always start the time measurement when the bubble is at the lowest marking of the calibrated tube.
    c. Select the measuring volume by choosing the appropriate soap bubble flow meter such that the time reading is more than 20 seconds.
    d. Take provisional readings of the flow rate. If the difference between successive readings within 5 to 15 minutes is less than 3%, take at least 2 readings in quick succession and determine the flow rate. Qi: V/ti

(m3/s) for the given pressure stage. If this condition is not reached within 3 hours (no constant flow is attained, e.g. very low-permeability concretes), take the previous value of the flow rate.

7. Increase the pressure to the next pressure level and repeat the procedure with steps (6a) through (6d). Ensure that there are no leaks during the tests: the coefficient K should decrease when the pressure increases. If this is not the case, check the test setup for possible leaks and repeat the measurements.

$$\mathbf{K}=\frac{2P_2QL\eta}{A(P_1^2-P_2^2)} \quad (3.5)$$

Where,

K: Gas permeability coefficient (m2)

P_1: Inlet gas pressure (N/ m2)

P_2: Outlet gas pressure (N/ m2)

A: Cross-sectional area of the sample (m2)

L: Height of sample (m)

η: Viscosity of oxygen ($2.02\text{x}10^{-5}$Nsn/ m2)

Q: Rate of flow of air bubble (m^3/sn)

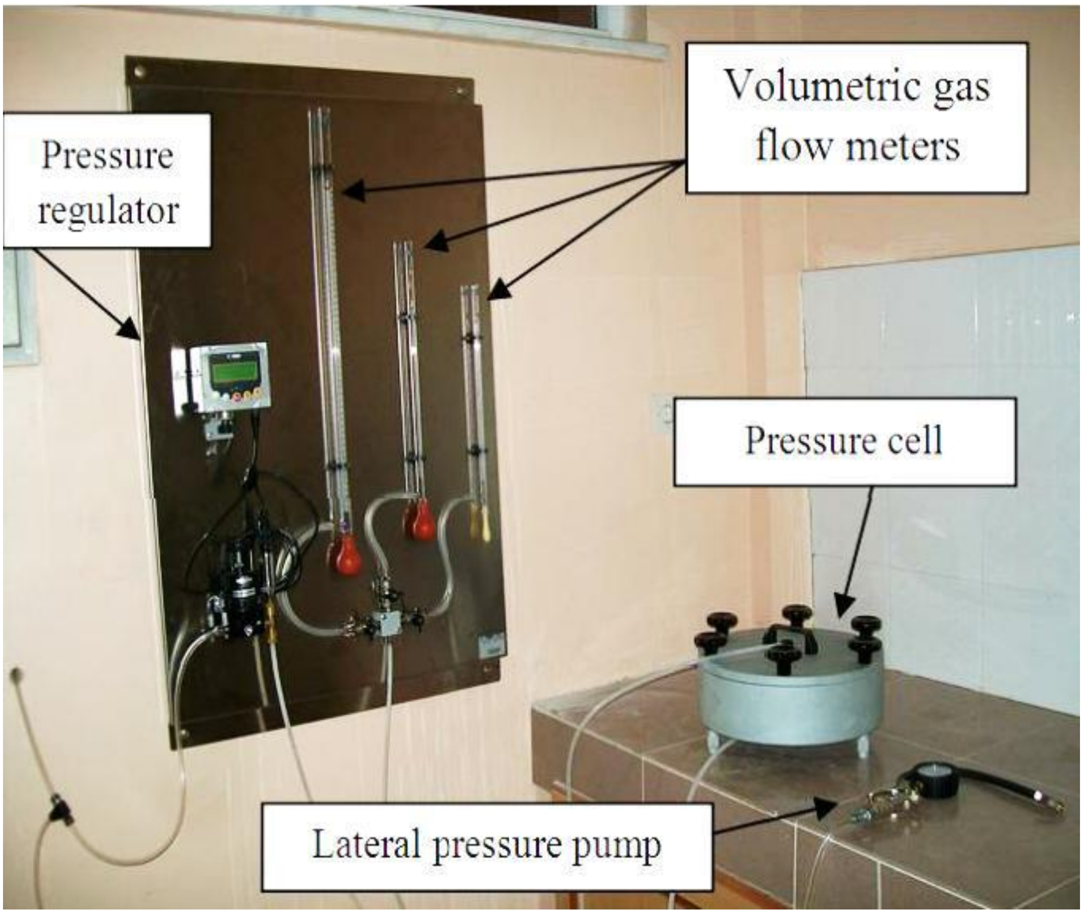

Figure 3.9Photographic view of the gas permeability test set up

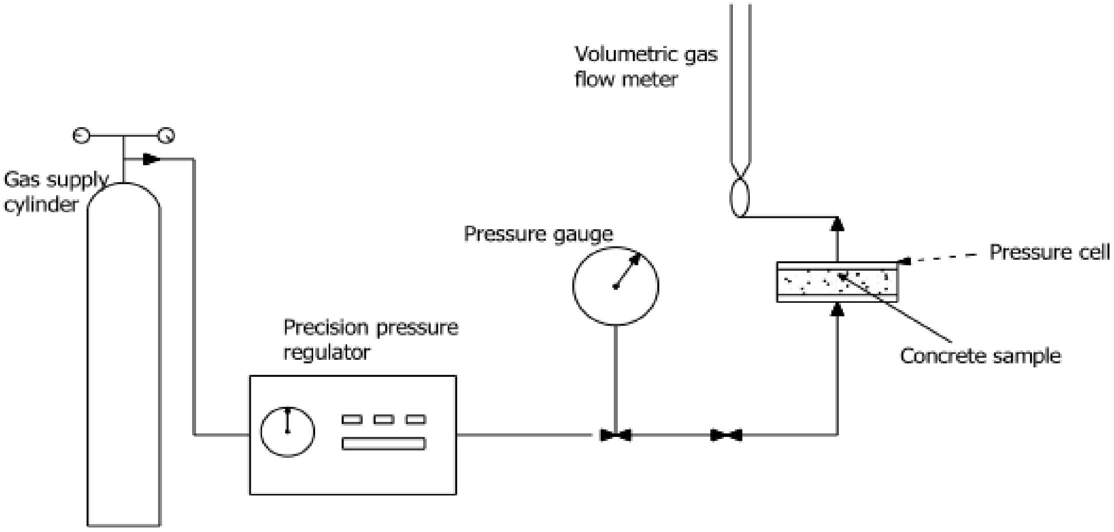

Figure 3.10Diagram presentation of the gas permeability test set up

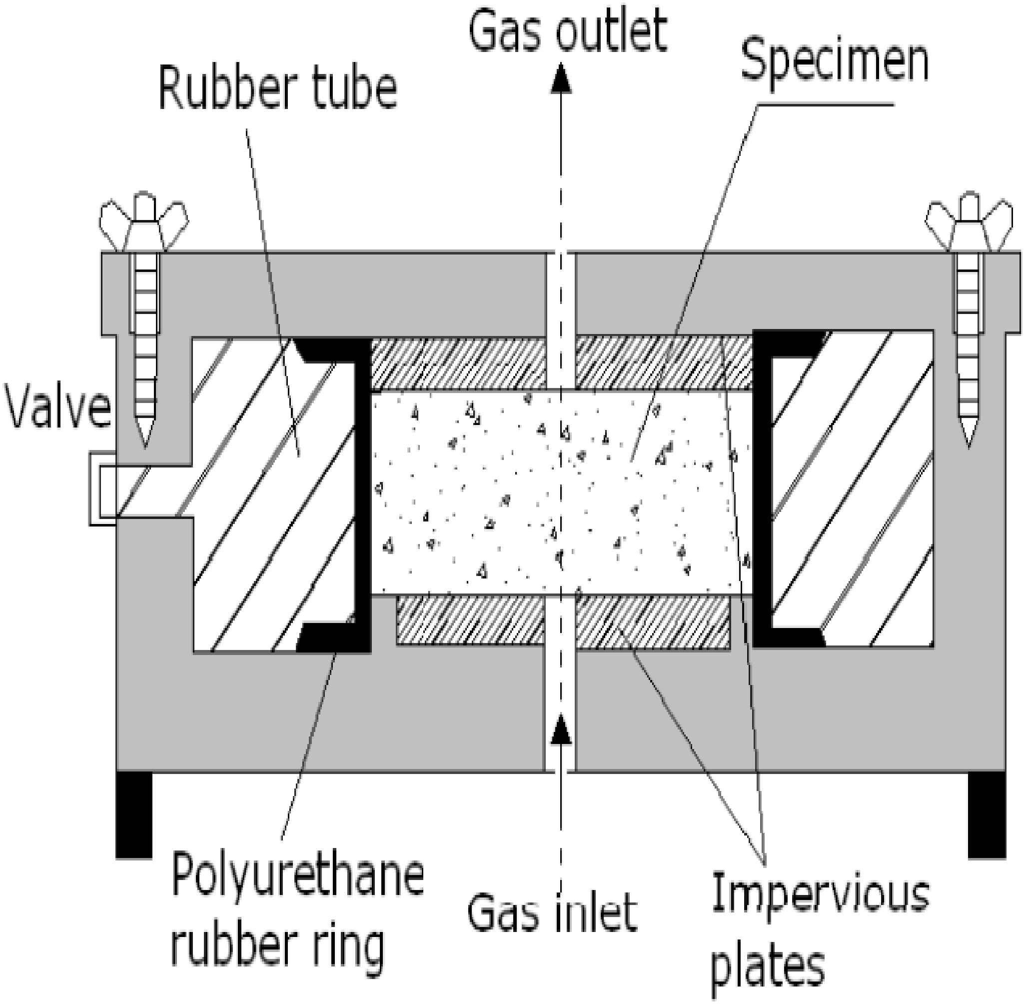

Figure 3.11Schematic presentation of the pressure cell and test specimen

CHAPTER 4

TEST RESULTS AND DISCUSSIONS

4.1. Compressive strength

The 28 and 90-day compressive strength versus the replacement level of rubberfor RSCCs with and without SFare given in Figure 4.1a andFigure 4.1b, respectively.The compressive strength of all concretes increased with increasing curing time. The results showed a systematicaldecrease in compressive strength with the increase in WRA for the concretes with and without SF. The overall compressive strength ranged from 61.6 to 82.7 MPa and from 68.2 to 87.4 MPa at 28 and 90 days, respectively. However, it was observed that these values significantly changed with the use of SF and WRA content. The concretes without SF had compressive strength reducing from 78.1 to 61.6 MPa and from 84.9 to 68.2 MPa at 28 and 90 days, respectively, with increasing WRA content. On the other hand, with the use of SF, the compressive strength decreased from 82.7 to 64.8 MPa and from 87.4 to 69.7 MPa at 28 and 90 days, respectively, with increasing WRA content from 0% to 40% by total medium aggregate volume. The results demonstrated that rubberized Self-compacting concretes with compressive strength of higher than 60 MPa may be produced by using a rubber content of as high as 40% replacement level by total medium aggregate volume. However for both 28 and 90 days, it was observed that there was about 21% reduction in compressive strength when 40% of the total medium aggregate volume was replaced by WRA, regardless of the SF content. The reduced compressive strength may, however, be attributed to two reasons as reported by (Khatip and Bayomy, 2013).First, because the rubber particles areWeaker and more elasticthan the surrounding cement paste, on loading, cracks are initiated quickly around the rubber particles in the mix. secondly, dueto the poor bond between the rubber particles and the paste,soft rubber particlesmay behave as voids in the concrete matrix. However, SF added to the mix improves the bond between the cement paste and the rubber particles as well as increasing the density of the cement paste, which is significantly improves the compressive strength of the SCRC (Mehta and Gjorv, 1982; Bentur et al., 1998; Cong et al., 1992). Therefore, in this study all mixtures showed the compressive strength more than 60 MPa at 28 and 90 days can be named as a high strength SCRC.It was demonstrated from the Figures 4.2 (a and b) that the specimens containing rubber particles fail gradually compare to the SCC without therubber particles. The mode of failure showed by the SCC is explosive and can bedangerous under dynamic loads such as impact loads since no prior notice will be given beforefailure.The SCRCs exhibit ductile failure because of the ability of withstanding loads beyond its capacity. The concrete containing 40% ofrubber particles replacement level by total medium aggregate volume undergoes the best failure mode by first initiating small cracks and gently fails underthe uniaxial compressive load, though it tends to display smaller amount of strength compare to the otherspecimens with smaller percentage of rubber particles.

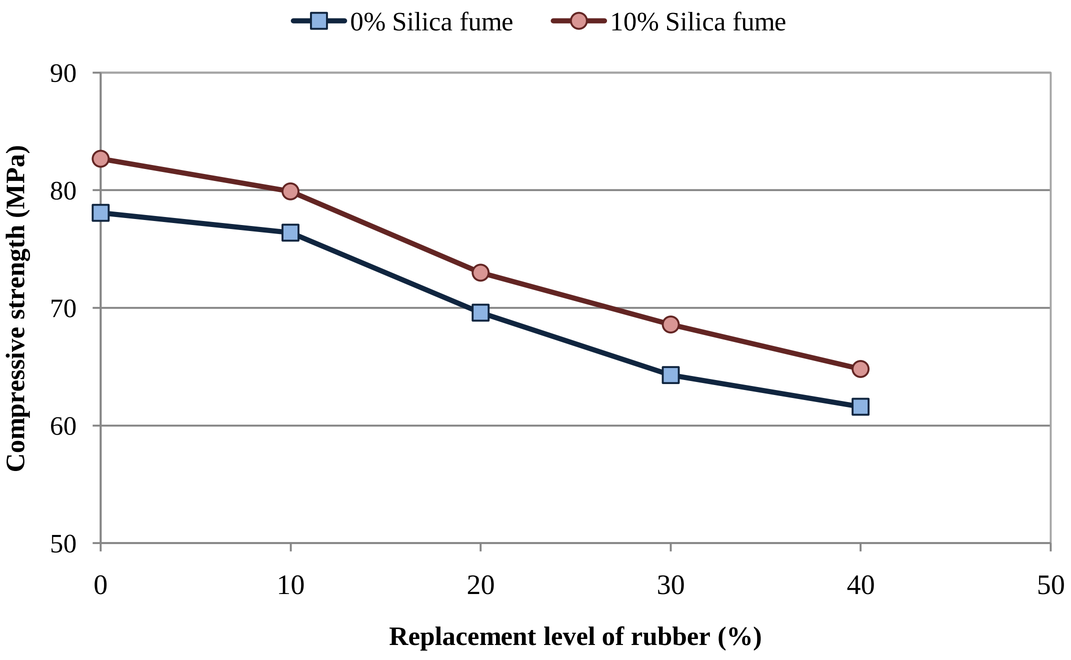

Figure 4.1a Variations in the compressive strength of SCRCs with and without SF at 28 days

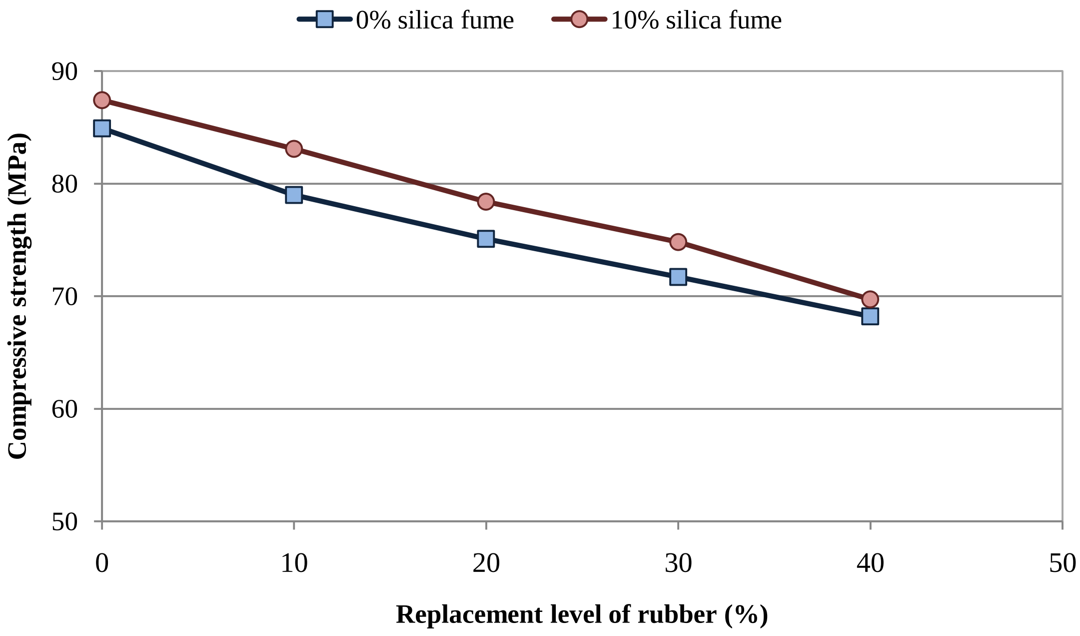

Figure 4.1b Variations in the compressive strength of SCRCs with and without SF at 90 days

Figure 4.2a Failure mode of SCC specimen without rubber particles under uniaxial compression

Figure 4.2b Failure mode of SCRC specimen with 40% rubber particles under uniaxial compression.

4.2. Splitting tensile strength

The90 day splitting tensile strength of the concretes is presented in Fig.4.3. The strength reduction pattern for the splitting tensile strength is similar to that of the compressive strength.Moreover, systematical decreasing in splitting tensile strength of SCRCs was also observed with increasing the rubber content The lowest splitting tensile strength value of 4.33 MPa was determined at SF0R40, whereas the maximum value of 6.41 MPa was measured at SF10R0. The concretes without SF had splitting tensile strength reducing from 6.08 to 4.33 MPa, with increasing rubber content. On the other hand, with the use of SF, the splitting tensile strength reduced from 6.41 to 4.48 MPa with increasing rubber content from 0% to 40% by total medium aggregate volume.However, it was observed that there was about 29% reduction in the splitting tensile strength when 40% of the total medium aggregate volume was replaced by rubber, regardless of the SF content.The test results showed that when SF was used it was an increase in splitting tensile strength from 3% to 7% for 40% to 0% replacement level of rubber content, this increase in splitting tensile strength is due to the finer particles of SF which improves the bond between rubber particles and the surrounding cement paste. The reduction in splitting tensile strength with increasing rubber content is attributed to the same factors which affect the compressive strength of specimens.

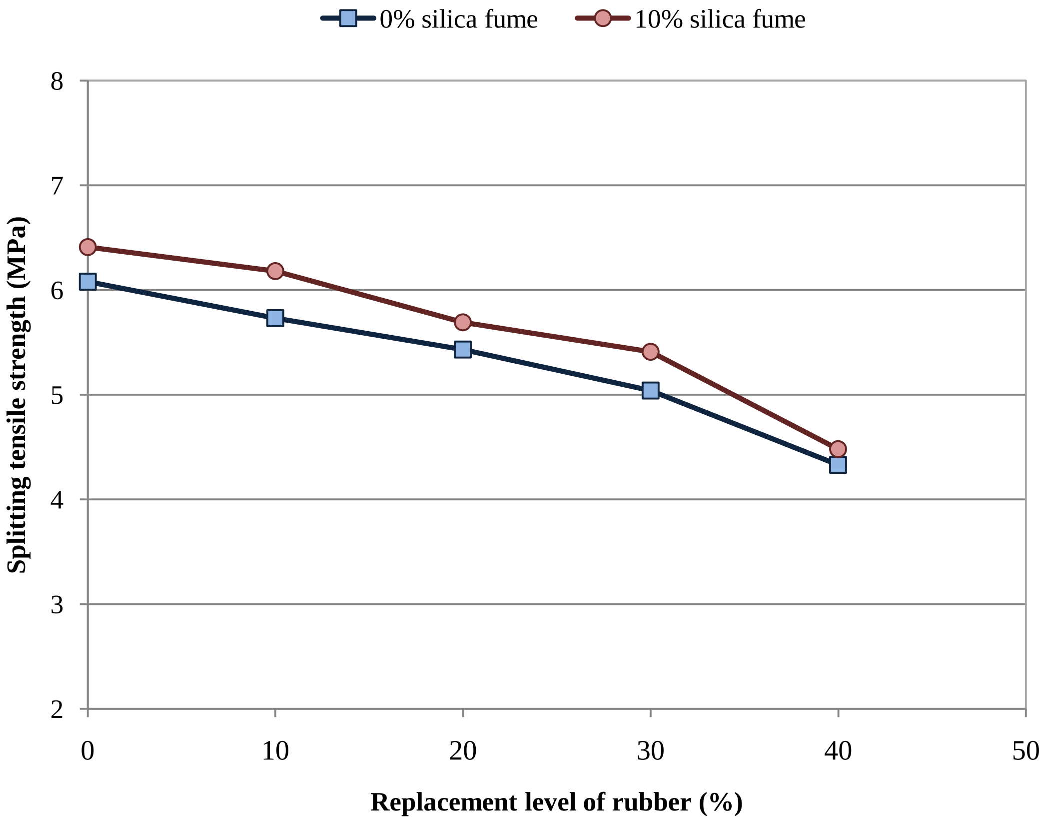

Figure 4.3Variations in the splitting tensile strength of SCRCs with and without SF at 90 days

4.3. Modulus of elasticity

The 90 day static elastic modulus test results as a function ofWRA and SF contents are presented in Fig. 4.4.The modulus of elasticity values ranging between 33.7 and 43.1 GPa were achieved in this study.The highest modulus of elasticity values were determined in the concretes produced without rubber content. However, the SCRCs with SF had slightly larger static elastic modulus from 35.7 to 43.1 GPa with regard to rubber content. Charts in Fig.4.4 demonstrated that static modulus of elasticity reduced with increasing WRA content in asimilarmanner to that observed in compressive strength and splitting tensile strength. With increasing the WRA content to 40% of the total medium aggregate volume it was a reduction of about 18% in static elastic modulus regardless of the SF content used. Apparently, the replacement of stiff medium aggregate with flexible rubber is the critical factor which affected the reduction in static elastic modulusobtained in this study.

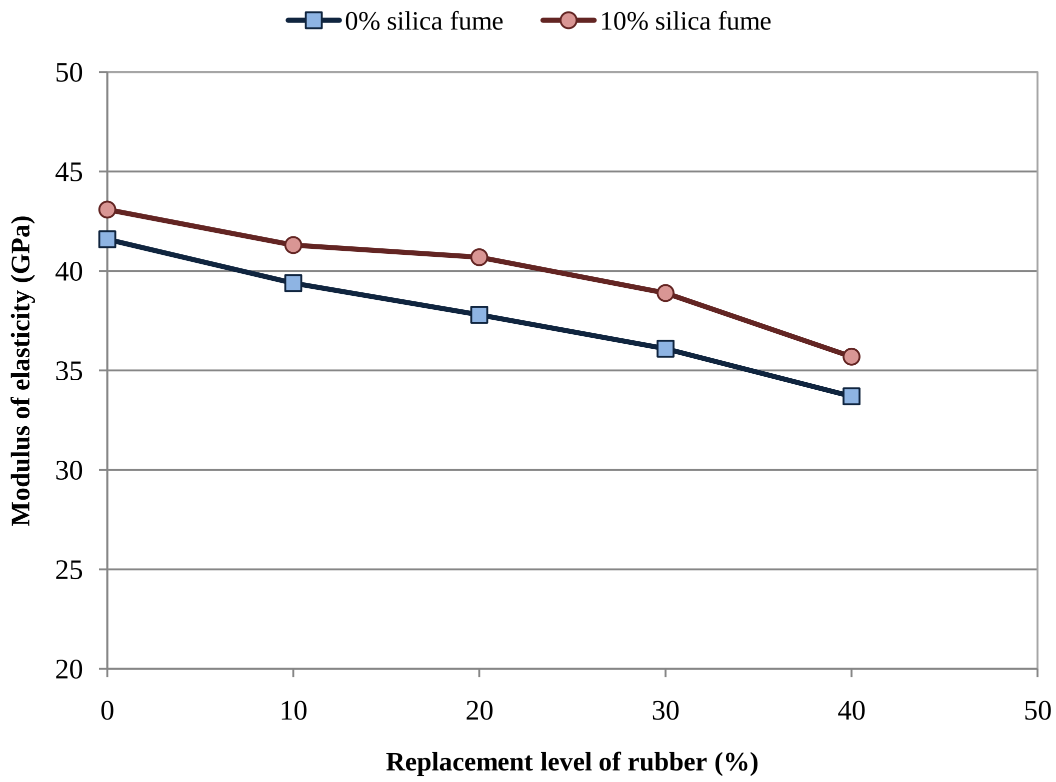

Figure 4.4Variations in the static modulus of elasticity of SCRCs with and without SF at 90 days

4.4. Fracture energy and characteristic length

The calculation of fracture energy consists of two parts; energy supplied by the actuator and by the own weight of the beam. The area under the load versus displacement curve is used in the calculation of fracture energy as the energy supplied by the actuator, and the weight of the beam is used in the calculation as the energy supplied by own weight of the beam. For SCRCs, the final displacement of the specimens is used in the calculation of energy supplied by own weight. Therefore, fracture energy (G_F) values at 90 days, evaluated with Equation 3.2 from notched beams subjected to three-point bending test was verifying versus rubber content volume fraction percentages at each of 0% and 10% SF. Figure 4.5 illustrates the variation in fracture energy of SCRCs with and without SF at various WRA volume fractions. Rubber particle addition increased the fracture energy of SCRC in both series.The figure clearly shows that the WRA had the notable effect on the fracture energy. Increasing WRA volume fraction from 0 to

40% increased the fracture energy from 89.9 to 98.8 N/m for SCRC without SF and from 80 to 91.9 N/m for SCRC with SF.Despite incorporating of SF decreased the fracture energy, the decreasing rate was about 11% regardless of rubber content.Typical loads versus displacement curves for SCRC at 0 and 10% SF contents are given in Figure 4.6 (a and b), respectively.The figures exhibited that withincreasing rubber contentthe ultimate load was decreased regardless of SF content.Moreover, it was observed that thearea under the load-displacement curve and displacement at the ultimate load was increased with increasing WRA volume fraction.This implied that the utilization of WRA in SCRC production made the composites more ductile and better strain capacity. Decrease the ultimate load and increase displacements due to the fact that the presence of rubber particles was expected to act like a hole at the crack tip and thus to reduce the tip sharpness of the first microcrack, resulting in stress relaxation and ultimately slowing down the kinetics of the first microcracks propagation. Such a mechanism is expected to delay microcrack coalescense and the resulting microcrack localization and to increase the displacement where the load-displacement curve starts to fall in the post peak zone (Turatsinze and Garros, 2008). Besides, it was noticed that incorporating SF increased the ultimate load of SCRC under three-point bending test but decreased the displacement at the ultimate load. This might be explained as substituting Portland cement with SF increased load carrying capacity of SCRC, however, it made the composite more brittle.

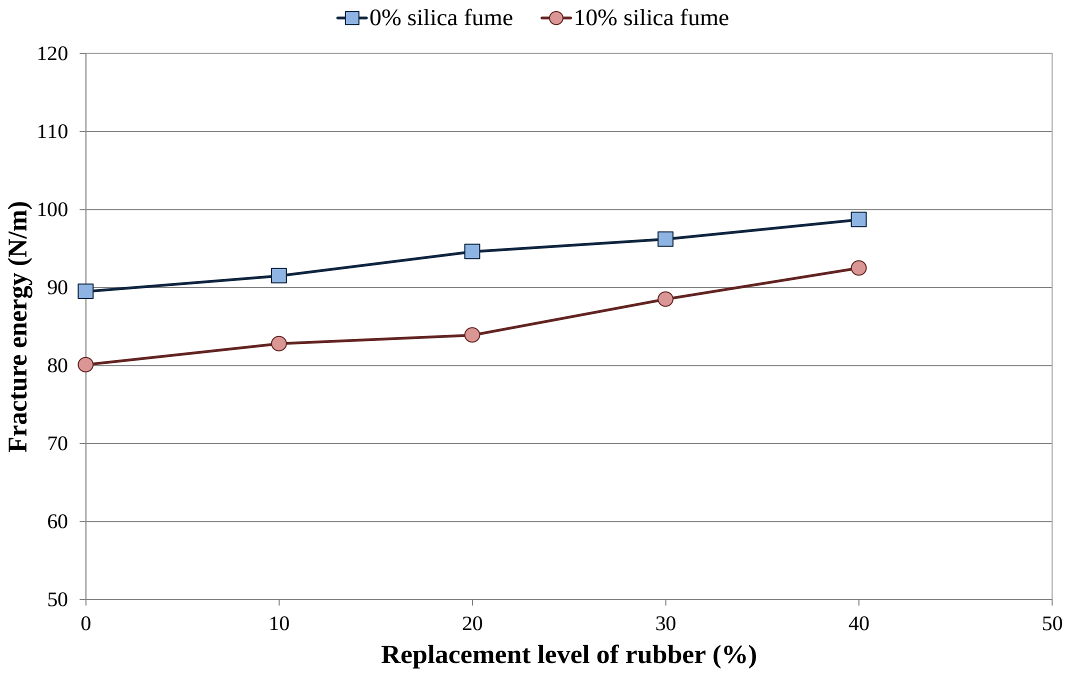

Figure 4.5Variation in the fracture energy coefficient of SCRCs with and without SF at 90 days

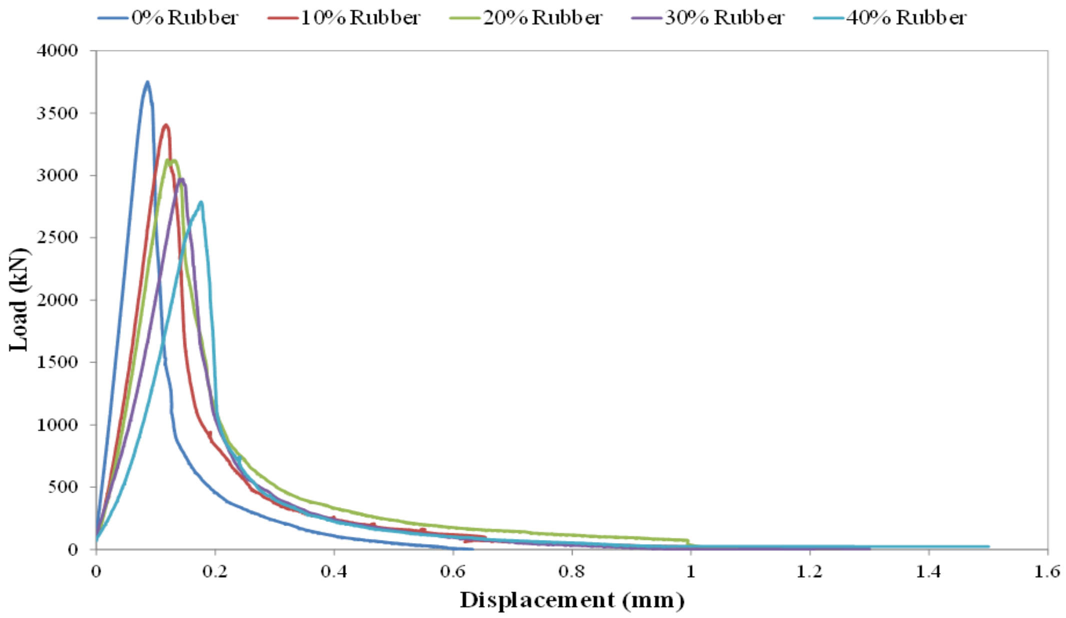

Figure 4.6a Load versus displacement curve for 0% to 40% WRA at 0% SF

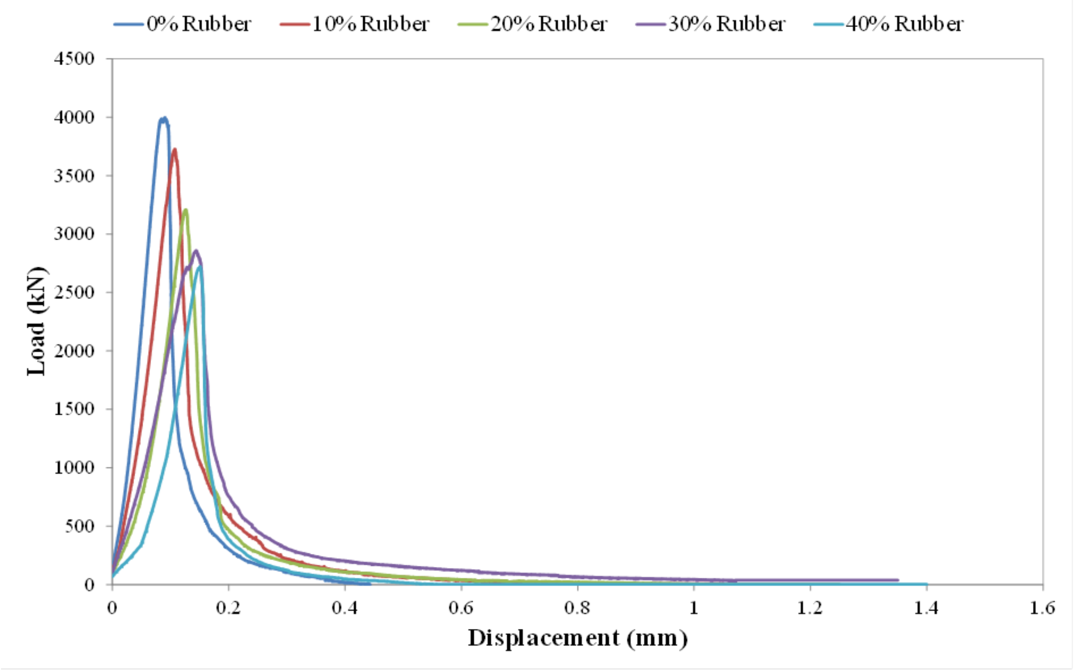

Figure 4.6b Load versus displacement curve for 0% to 40% WRA at 10% SF

The characteristic length of SCRC, which is the indication of brittleness of concrete, versus WRA volume fraction presents in Figure 4.7. The results showed that by increasing the rubber content the characteristic length of SCRC increased. This also indicated that WRA addition made SCC more ductile. The results also revealed that SF incorporating yielded the lower characteristic length values that meant SCRC composites containing SF were more brittle than the composite did not include SF.

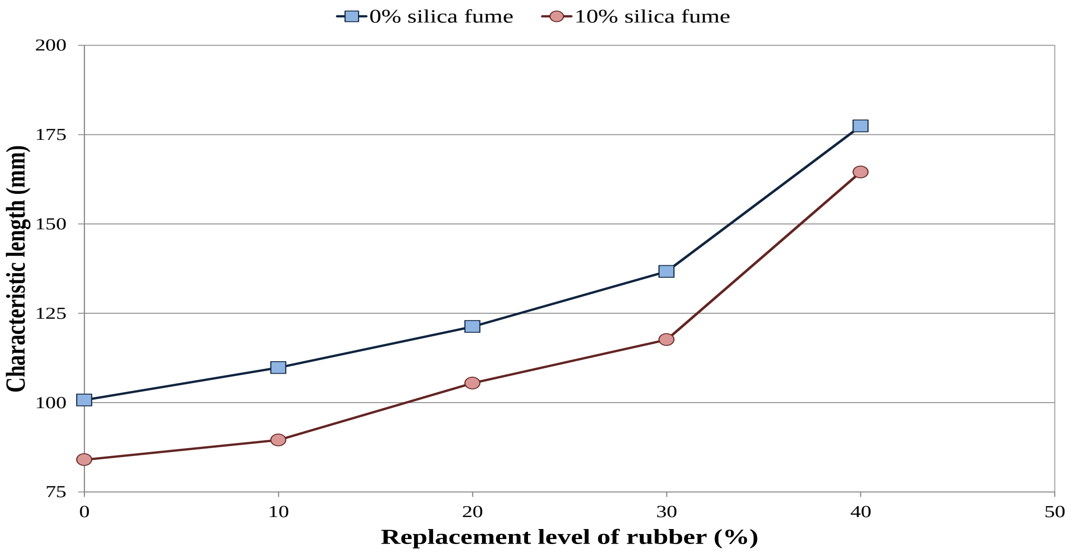

Figure 4.7Variation in the characteristic length of SCRCs with and without SF at 90 days

4.5. Net flexural strength

Net flexural strengths obtained from three-point bending test on the notched specimen versus rubber content volume fraction at 90 day are presented in Figure 4.8. The results indicated that WRA had remarkable influence on the tensile strength of SCC. The similar trend in splitting tensile strength was observed for the net flexural strength of SCC. The net flexural strengths of SCC without rubber particles were 6.12 and 6.31 MPa at 0 and 10% SF contents, respectively. Systematical decreasing in the net flexural strength was obtained when the volume fraction of WRA increased from 0 to 40% by total medium aggregate volume there was about 16% reduction in the net flexural strength when 40% of the total medium aggregate volume was replaced by rubber, regardless of the SF content.However, smooth texture and low bonding of rubber particles has significant effect in reducing flexural strength of SCRC. The highest net flexural strengths were observed in SCC including SF. Incorporating SF resulted in higher net flexural strength as in the splitting tensile strength due to enhancement the bond between cement paste and rubber particles.

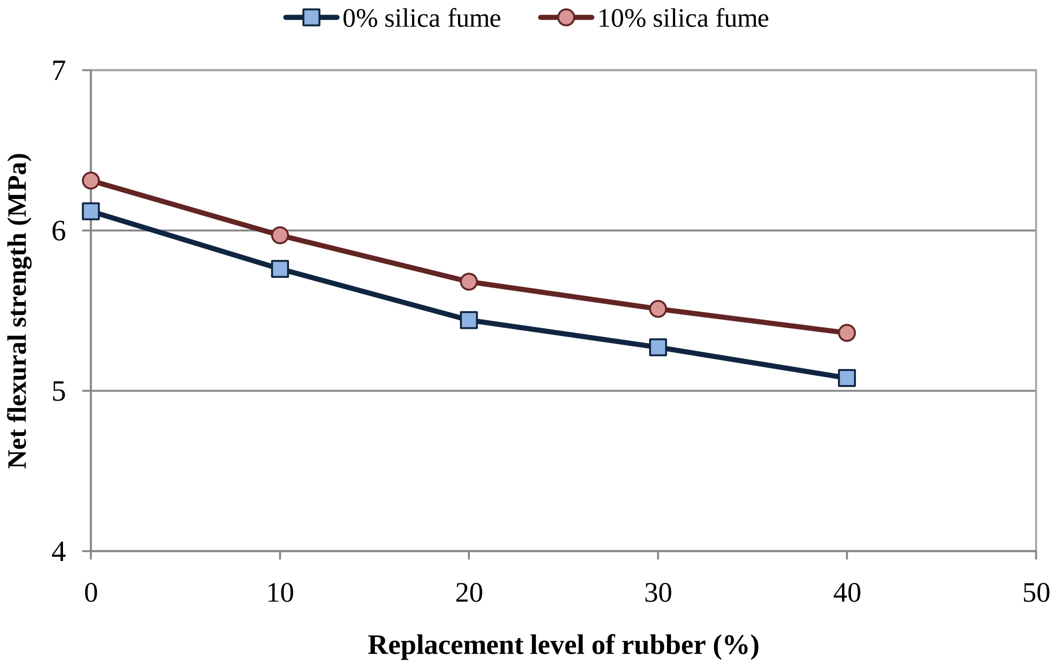

Figure 4.8Variations in the net flexural strength of SCRCs with and without SF at 90 days

4.6. Water sorptivity

The water sorptivity of a concrete is influenced by many of factors containing concrete mixture proportions, the use of supplementary cementitious materials and chemical admixtures, the physical characteristics and composition of the cementitious components and of the aggregates, the entrained air content, the duration and type of curing, the age or degree of hydration, the presence of microcracks, and the presence of surface treatments for instance sealers or form oil, and placement method including compaction and finishing(Gesoğlu and Güneyisi,2011).The 28 and 90-dayssorptivitycoefficients versus the replacement level of rubber for SCRCs with and without SF are given in Figure 4.9a and Figure 4.9b, respectively. the results showed that sorptivity increases with increasing the rubber content for SCRCs with and without SF, regardless of the testing age, it could be due to the higher initial water absorption of rubbers compared to natural aggregates. The SCRCs manufactured with ternary cementitious blends performed better than that produced with binary cementitious blends.The concretes without SF had a sorptivity coefficients from 0.0838 to 0.0971 mm/min$^{0.5}$ and from 0.0742 to 0.0912 mm/min$^{0.5}$at 28 and 90 days, respectively, with increasing WRA content.On the other hand, with the addition of SF, the concretes had a sorptivity coefficients from 0.0689 to 0.0883 mm/min$^{0.5}$ and from 0.0577 to 0.0788mm/min$^{0.5}$ at 28 and 90 days, respectively, with increasing WRA content from 0% to 40% by total medium aggregate volume.However, it was observed that when SF was used the sorptivity coefficient reduced of about 17% irrespective of rubber content and testing age. This reduction could be due to the denser microstrucrure of the specimens as a result of the filler effect of the SF fine particles and the additional pozzolanic hydration products. However, the reduction in sorptivity coefficients at 90 days for all mixtures due to the refined pore structure of the concretes attributed to pozzolanic long-term effect of FA.

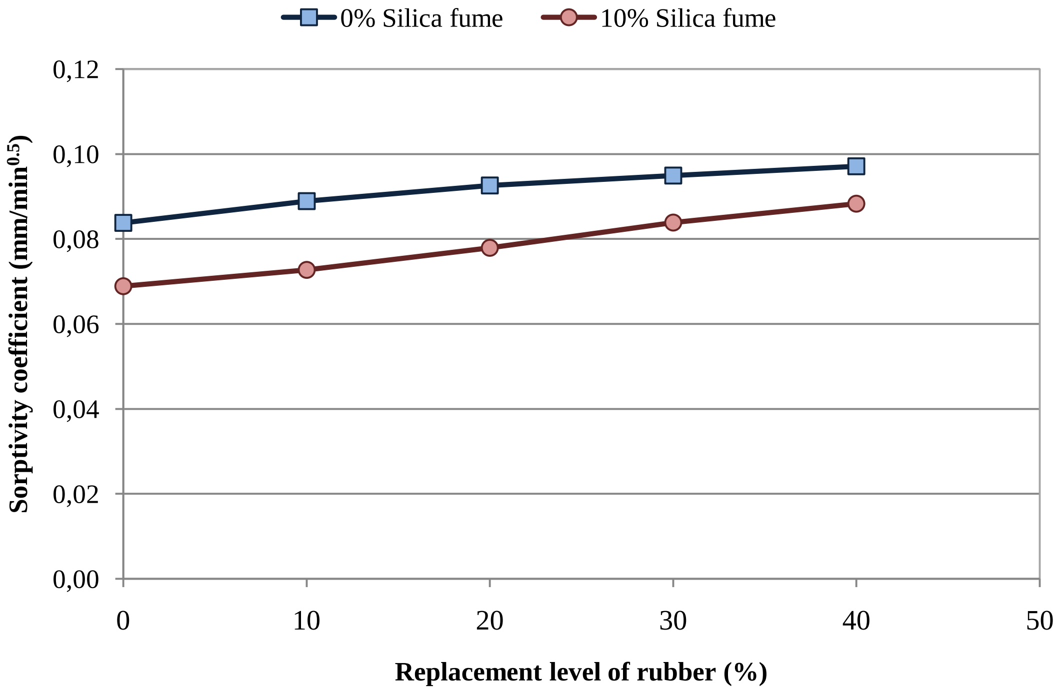

Figure 4.9a Variations in the sorptivity coefficient of SCRCs with and without SF at 28 days

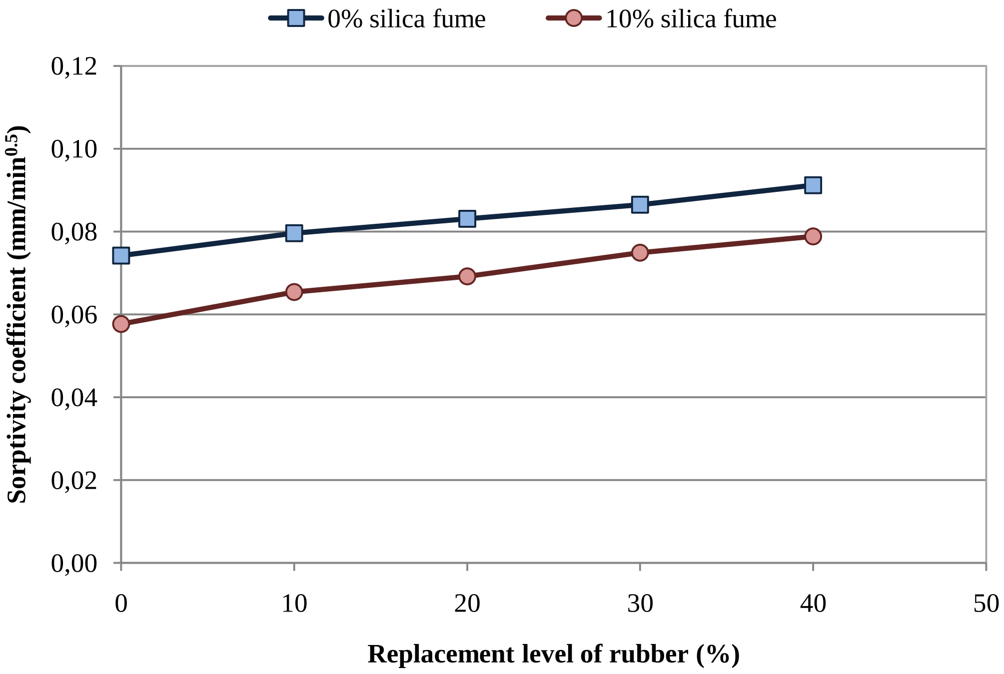

Figure 4.9b Variations in the sorptivity coefficient of SCRCs with and without SF at 90 days

4.7. Rapid chloride permeability

The chloride ion permeability test results as a function of rubber particles and SF contents as well as testing age are presentedin Fig.4.10a and Fig4.10b, respectively. The resultsdemonstrated that the chloride ionpermeability of the SCRCs were in the range of 1092 to 4183 Columbus and 510 to 2993 Columbus at 28 and 90 days,respectively.There was a vital increase in the chloride ion penetration with the increasingrubber content, regardless of the testing age, especially for the concretes without SF.The concretes without SF had a chloride ion penetration from 3070 to 4183columbus and from 2387 to 2293columbus at 28 and 90 days, respectively, with increasing rubber content, these results considered as “high to moderate” ion penetration at 28 and 90 days, respectively, advising to the classification of concrete for chloride permeability, as showed in the Table 3.5, which is classified according to ASTM C1202 as mentioned before. On the other hand, with the use of SF, the concretes had a chloride ion penetration from 1092 to 1850Columbus and from 510 to 949 Columbus at 28 and 90 days, respectively, with increasing rubber content from 0% to 40% by total medium aggregate volume, also these results considered as “low to verylow” chloride ion penetration. However, it was observed that when SF was used the chloride ion penetration reduced of about 60% irrespective of rubber content at 28 day testing age, also at 90 days when SF was used the chloride ion penetration reduced of about 73% irrespective of rubber content, it means that using SF shifted the rating of the concretesfrom high to low and from moderate to verylow at 28 and 90 days, respectively, regardless of testing age and rubber content.The low permeability ofthe concretes with mineral admixtures may be attributed to transformationlarge pores to fine pores or pore refinement due to filler effects of SF and FA especially at 90 days because of the long-term reaction of FA which refines the porestructure of concrete(Gesoğlu and Güneyisi, 2011).

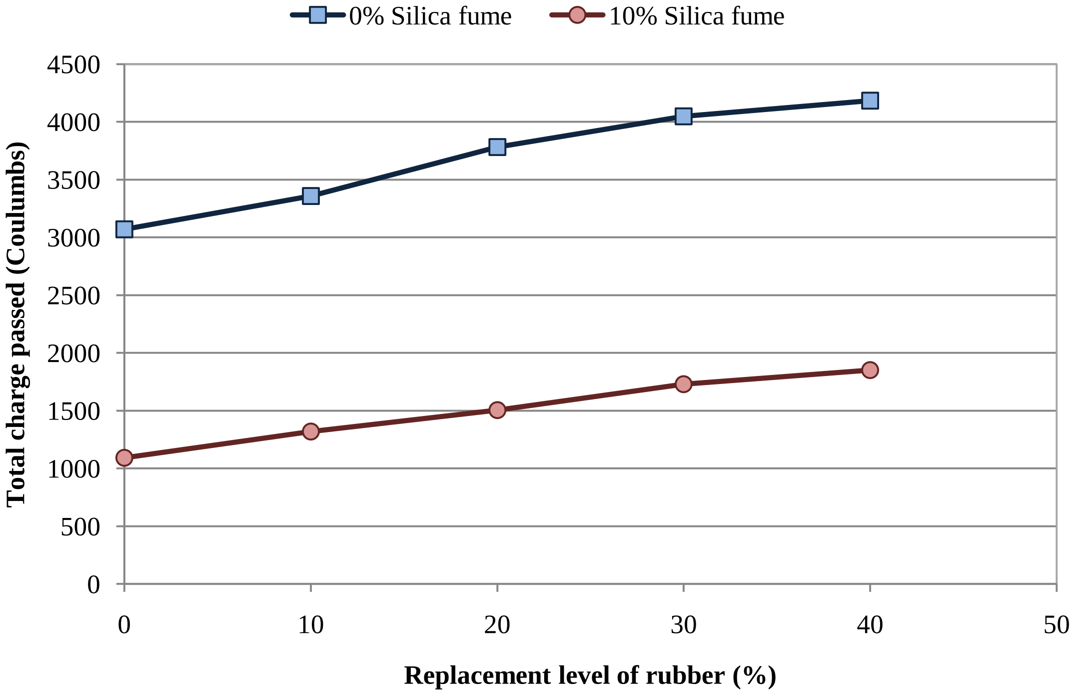

Figure 4.10a Variations in the chloride ion permeability of SCRCs with and without SF at 28 days

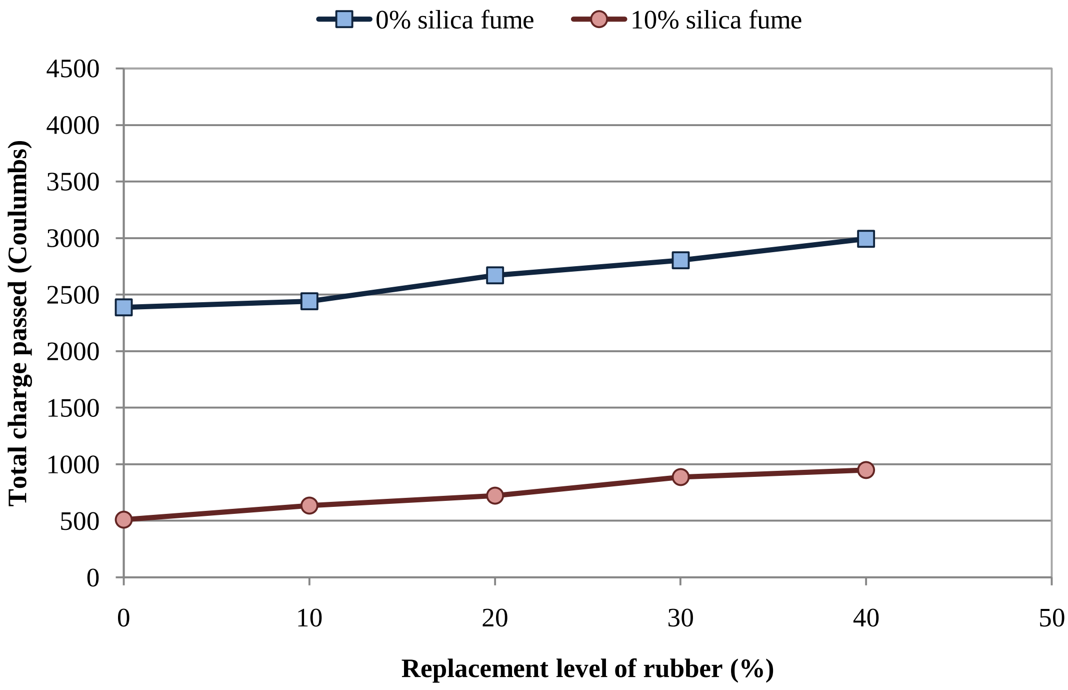

Figure 4.10b Variations in the chloride ion permeability of SCRCs with and without SF at 90 days

4.8. Gas permeability

The behavior of SCRC at 28 and 90 day of apparent gas permeability test results as a function of WRAand SF contents are illustrated in Fig.4.11a and Fig4.11b, respectively.according to the inlet pressure head.The apparent gas permeability determination was conducted onthe idia of the Hagen–Poiseuille relationship for laminar flow ofa compressible fluid through a porous body with small capillariesunder steady-state conditions(Kollek JJ, 1989).A RILEM TC 116 (1999) recommends theuse of 150, 200, and 300 kPa inlet pressures for calculation ofthe average gas permeability coefficient.The results showed that the gas permeability coefficients increases with increasing the WRA content for SCRCs with and without SF, regardless of the age testing. The SCRCs produced with ternary cementitious blends had better resistance compared with binary cementitious blends. The concretes without SF had a gas permeability coefficients from 3.22-5.38 ($x10^{-16}$) m^2 and from 2.49-5.01($x10^{-16}$) m^2 at 28 and 90 days, respectively, with increasingWRA content. On the other hand, with the addition of SF, the concretes had a gas permeability coefficients from 2.57-5.03 ($x10^{-16}$) m^2 and from 2.09-4.21 ($x10^{-16}$) m^2 at 28 and 90 days, respectively, with increasing WRA content from 0% to 40% by total volume of medium aggregate. However, it was observed that when SF was used as the ternary cementitious blend the gas permeability coefficient reduced of about 4.5% at 28 day irrespective of rubber content. Though at

90 day the ternary cementitious blends seemed to be more effective in the reductionof the apparent gas permeability coefficients and it reduced of about 10.5% due to long-term pozzolanic reaction of FA.

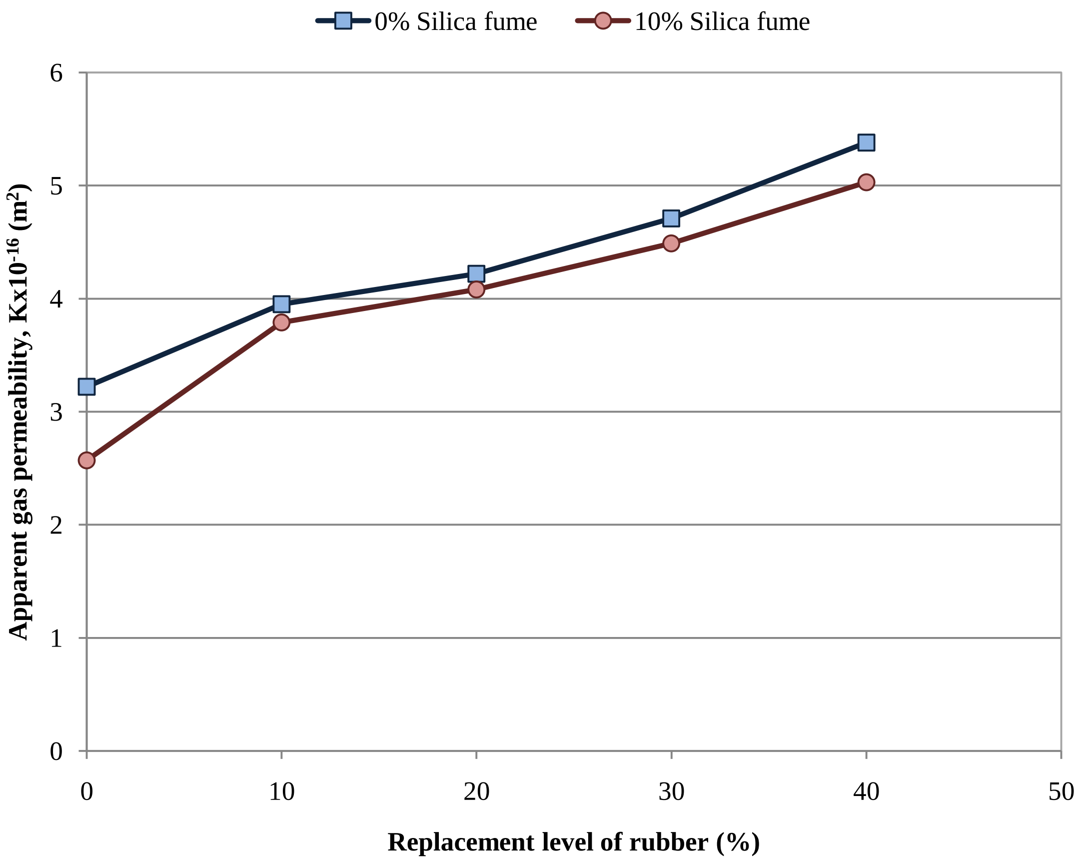

Figure 4.11a Variations in the gas permeability of SCRCs with and without SF at 28 days

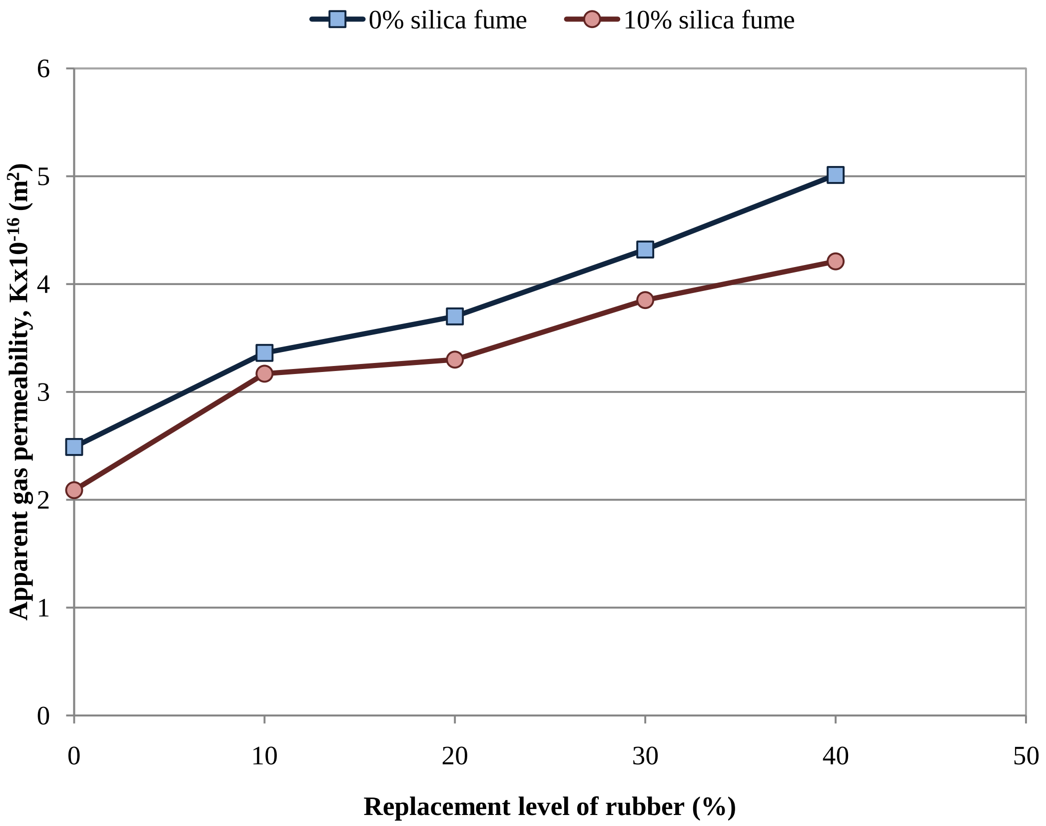

Figure 4.11b Variations in the gas permeability of SCRCs with and without SF at 90 days

CHAPTER 5

CONCLUSIONS

Based on the results presented in this investigation, the following conclusions can be drawn:

- The compressive strengthof SCRC was significantly reduced with increasing the rubber content, regardless of testing age. However, the addition of SF into the mix significantly improvedthe bond between the paste and the WRA particles, which is significantly enhances the compressive strength of the SCRC.However, the test results showed that it was possible to produce a high-strength rubberized concrete with a high-strengthand compressive strength more than 60 MPa with the WRA content up to 40%replacement level by total medium aggregate volume.

- The elastic modulus of SCRC indicated the same trend with the compressive strength and splitting tensile strength. With increasing the WRA content to 40% of the total medium aggregate volume it was a reduction of about 18% in static elastic modulus regardless of the SF content used. Apparently, the replacement of stiff medium aggregate with flexible rubber is the critical factor which affected the reduction in static elastic modulus obtained in this study.

- There was a systematical decreasing in both splitting tensile and net flexural strengths of SCC as rubber volume fraction increased. The results of splitting tensile and net flexural strengths indicated that WRA had negative influence on the tensile characteristic of SCC. Moreover, SF blended SCC series had the higher tensile strength than SCC without SF.

- The fracture energy of SCRC was systematically increased by increasing WRA volume fraction. Moreover, SCRC including rubber particles had a lower ultimate load and higher displacements under three-point bending test. Additionally, SF incorporation decreased fracture energy and increased ultimate load of SCC. The results on the characteristic length of SCC indicated that the utilization of WRA in SCC production enhanced the ductility of the composite. However, replacing cement with SF decreased the characteristic length of SCC.

- The sorptivity coefficients of the SCRC mixtures were increased by increasing the of rubbercontent, regardless of thetestingage. However with the addition of SF, the negativeeffect of rubber particles on the sorptivity coefficients reduced slightly. On the other hand, The reduction amount increased at 90 days for all mixes resulting from the refined pore structure of the concretes attributed to pozzolanic long-term influence of FA.

- The chloride ion penetration resistance of SCRC according to the total charge passed was significantly decreased by increasing the rubber content. However, the SF utilization considerably improved the resistance of the SCRC mixtures to chloride ion penetration. Addition of SF shifted the rating of the ion penetration into the concretes from high to low and from moderate to verylow at 28 and 90 days, respectively, regardless of testing age and rubber content.

- It is proved that the gas permeability coefficient were increased by increasing rubber content. Combination of mineral additives isefficientin the reduction of apparent gas permeability. Combination ofblends in ternary system enhanced the quality of SCRCs, especially at 90 days due to its pozzolanic activity and void filling ability of SF and FA.

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