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EFFECT OF RECYCLED GRANULAR POLYETHYLENE TEREPHTHALATE (PET) ON FRESH AND HARDENED PROPERTIES OF SELF CONSOLIDATING CONCRETE

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IN
CIVIL ENGINEERING

by
Mehmet SAKİN

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Effect of recycled granular Polyethylene Terephthalate (PET) on fresh and hardened properties of self-consolidating concrete

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Assist. Prof. Dr. Kasım MERMERDAŞ

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Mehmet SAKİN

ABSTRACT

EFFECT OF RECYCLED GRANULAR POLYETHYLENE TEREPHTHALATE (PET) ON FRESH AND HARDENED PROPERTIES OF SELF CONSOLIDATING CONCRETE

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January 2015

In this thesis, an experimental program was conducted to investigate some mechanical, physical, durability and fresh properties of self-consolidating concretes made with waste granular polyethylene terephthalate (PET). Although there are various recycling methods for PET, using PET wastes in concrete production for which high volumes of aggregate is needed concrete may also be considered as an effective solution. In this study, utilization of PET granules obtained by crushing waste PET bottles as fine aggregate for production of self-consolidating concrete (SCC) is investigated. PET granules that are passed through 4 mm sieve were used in SCC production as fine aggregate replacement by volume. The effect of PET on the fresh properties of SCC was examined. The inspected fresh properties are flow diameter, $T_{50\ cm\ flow}$ time, and V funnel flow time. The compatibility of the produced SCC specimens that have PET aggregate to EFNARC (European Federation of National Associations Representing for Concrete) criteria was discussed. Additionally, 28-day compressive strength test, splitting tensile strength test results were also presented in order to discuss the effect of PET aggregate on the mechanical properties of SCC. Water absorption and sorptivity results were conducted to observe the effect of PET on the permeability of SCC produced. The results indicated that using PET granules in production of SCC resulted in deterioration of workability of SCC. However, there were no significant changes in the mechanical and absorption characteristics of SCC.

Key Words: Self Consolidating Concrete, Fresh Properties, Hardened Properties, Mechanical Properties.

ÖZET

ATIK POLİEİTİLEN TEREFTALAT (PET) GRANÜLLERİNİN KENDİLİĞİNDEN YERLEŞEN BETONDA TAZE VE SERTLEŞMİŞ ÖZELLİKLERİNİN İNCELENMESİ

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Bu tez çalışmasında, farklı oranlarda polietilen tereftalat (PET) kullanımının kendiliğinden yerleşen betonun (KYB) taze özellikleri ile bazı sertleşmiş özellikleri üzerindeki etkisi deneysel olarak araştırılmıştır. PET atıklarla ilgili çeşitli geri dönüşüm çalışmaları yapılmakla beraber, yüksek hacimde agrega ihtiyacı olan betona katılması da etkili bir çözüm önerisi olmaya adaydır. Bu çalışmada PET şişe atıklarının kırılmasıyla elde edilen granüllerin kendiliğinden yerleşen beton (KYB) üretiminde ince agrega olarak kullanılabilirliği araştırılmıştır. 4 mm'lik elekten geçirilen PET kırıkları KYB'de ince agrega ile hacimce yer değiştirilerek kullanılmış ve üretilen betonların taze özellikleri üzerindeki etkileri incelenmiştir. İncelenen taze özellikler yayılma çapı, $T_{50\ cm}$ yayılma süresi, L kutusu yükseklik oranıdır. Üretilen PET agregalı KYB'lerin EFNARC (European Federation of National Associations Representing for Concrete) kriterlerine uygunluğu tartışılmıştır. Bunların yanı sıra PET agregası kullanımının KYB'lerin basınç ve yarma dayanımı üzerindeki etkisini tespit etmek amacıyla 28. günde deneyler yapılmıştır. Ayrıca, PET agregaların KYB numuneleri üzerindeki su emme kapasitesi ve kılcal su geçirimlilik değerleri incelenmiştir. Elde edilen sonuçlara gore, PET kullanımı KYB'nin işlenebilme özelliklerini kötüleştirirken sertleşmiş özellikler üzerinde de etkili olduğu tespit edilmiştir.

Anahtar kelimeler: Polietilen tereftalat (PET), kendiliğinden yerleşen beton (KYB), taze özellikler, mekanik özellikleri, sertleşmiş özellikleri.

To My Family…

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LIST OF SYMBOLS/ABBREVIATIONS

A Cross-sectional area of the sample

a The notch depth of beam

ASTM American Society for Testing and Materials

B The width of beam

CC Conventional Concrete

E Static modulus of elasticity

EFNARC European Federation of National Associations Representing for Concrete

fc Cylinder compressive strength

fst Splitting tensile strength

g Gravitational acceleration,

GGBS Ground granulated blast furnace slag

HRWRA High Range Water Reducing Admixture

PET Polyethylene Terephthalate

L Height of sample

OPC Ordinary Portland Cement

R Radius of the disc

S The span of beam

S’ Sorptivity index

SCC Self Consolidating Concrete

SP Super plasticizer

t Time

T500mm The time required to reach 500 mm slump-flow

σ	Crushing strength
τ	Shear stress

CHAPTER 1

INTRODUCTION

1.1 General

Self-compacting concrete (SCC) has emerged in Japan in the late 1980s as a material that can flow under its own weight, completely filling formwork, and achieving full compaction, even in the presence of congested reinforcement. The hardened concrete is dense, homogenous and has the same engineering properties and durability as traditional concrete (Nehdi et al., 2004). The purpose of SCC concept is to decrease the risk due to the human factor, to enable economic efficiency, less human work, more freedom to designers and constructors, to lower noise level on the construction site. The common practice to produce SCC is to limit the coarse aggregate content associated with its maximum size and to use the lower water-binder ratios together with appropriate super plasticizers (Okamura and Ozawa, 1995). In order to achieve a SCC of high fluidity and to prevent the segregation and bleeding during transportation and placing, the formulators have employed a high volume of Portland cement and chemical admixtures (Lachemi et al., 2004). In some cases, the saving in labor cost might offset the increased cost. But the use of mineral admixtures such as fly ash, ground granulated blast furnace slag, marble powder, limestone filler, etc. reduced the material cost of the self – compacting concretes and also improved fresh and hardened properties of the concretes. Using mineral admixtures especially in SCC necessitates further attention. On incorporation of such materials, certain properties of the concretes may be enhanced whereas others may worsen relative to the plain Portland cement concrete. Recycling PET waste bottles as PET fibers to make fiber reinforced concrete has been considered in many researches. The volume of fiber content with respect to fiber concrete is between 0.3% and 1.5%. So, this procedure recycles small amount of plastic PET wastes (Foti D, 2011). The most economical way is using PET particles as a substitute of aggregates and mortar. As a result, using PET waste as an aggregate in concrete has some benefits such as decreasing the usage of natural resources, the wastes consumption, preventing the environmental pollution and economizing energy.

The main objective of the thesis presented herein is to investigate the properties of the self-compacting concretes made with the waste granular polyethylene terephthalate (PET). For this purpose, fresh properties of SCCs were observed through slump flow time and flow diameter, V-funnel flow time. The rheological properties of each mixture were also determined by using ICAR rheometer equipment. Hardened properties of SCCs were tested for compressive strength, splitting tensile strength, net flexural strength, sorptivity, water absorption performance.

1.2 Outline of the thesis

Chapter 1 – Introduction: Aim and objectives of the thesis are introduced.

Chapter2 – Literature review: A literature survey was conducted on self compacting concrete and waste granular polyethylene terephthalate (PET).

Chapter 3 – Experimantal study : Materials , mixtures, casting, curing conditions, and test methods are described.

Chapter 4 – Test results and discussions : Indication, evaluation, and discussion of the test results are presented.

Chapter 5 – Conclusion : Conclusion of the the thesis and recommendation for future studies are given.

CHAPTER 2

LITERATURE REVIEW AND BACKROUND

2.1 Recycling in concrete technology

A modern lifestyle, alongside the advancement of technology has led to an increase in the amount and type of waste being generated, leading to a waste disposal crisis. That is generated from construction fields, such as demolished concrete, glass, and plastic. In order to dispose of or at least reduce the accumulation of certain kinds of waste, it has been suggested to reuse some of these waste materials to substitute a percentage of the primary materials used in the concrete. The waste materials considered to be recycled in consist of glass, plastics, and demolished concrete. Such recycling not only helps conserve natural resources, but also helps solve a growing waste disposal crisis. Ground plastics and glass were used to replace up to 20% of fine aggregates in concrete mixes, while crushed concrete was used to replace up to 20% of coarse aggregates. To evaluate these replacements on the properties of the OPC mixes, a number of laboratory tests were carried out (Batayneh M. et al., 2007).

2.2 Waste materials used in concrete

2.2.1 Cementing Materials

2.2.1.1 Fly Ash

Pozzolans including siliceous and/or alumina materials hold little or no cementitious value by themselves. However, in existence of humidity, in a finely divided shape, it reacts with calcium hydroxide in chemical way in order to create composites with cementitious features at any temperature. Fly ash is the best known, and one of the most commonly used pozzolans in the world. Fly ash is inorganic waste product generated during the firing of (nearly 1200 ^{O}C) powder coal particles in thermal power stations, which is capable of reacting with $Ca(OH)_2$ at room temperature so as to create cementitious composites. The presence of SiO_2 and Al_2O_3 in amorphous form affects the pozzolanic activity of fly ash (Baker, 1984; Naik and Singh, 1995; Baykal et. al, 1997). Characteristics of the fly ash depends on numerous factors, such as type of power plant, the composition of feed coal, chemical composition of the coal and burning system, and conditions of deposition of fly ash.

2.2.1.2 Silica Fume

Silica fume (SF) is a highly reactive mineral admixture composed of very fine particles of silica predominantly in the amorphous state. Indeed, the major chemical compound, usually taking up more than 80% of the silica fume, is SiO_2, details depending on the manufacturing process (Pistille M.F, 1985). The particles of silica fume have a size smaller than 0.1 μm.

2.2.1.3 Ground granulated blastfurnace slag (GGBS)

Ground granulated blastfurnace slag (GGBS) is a by-product of the steel industry. During the production of iron, a composite of iron-ore, coke, and limestone is fed into the blastfurnace, whereby iron-ore is reduced to iron and separated from the remaining slag. The slag is tapped- off and cooled rapidly to retain its cementitious properties. It is then dried and ground to an appropriate fineness (GGBS) for use as a cementitious material. Currently, the price of GGBS in China is only about 60–80% of that of PC. The generation of 1 tonne of GGBS uses nearly 1300 MJ of energy and induces approximately 0.07 tonne of CO_2 emissions (Higgins, 2007); these values are much lower than those associated with PC production.

2.2.1.4 Rice husk ash

Rice husk ash (RHA) is a product produced by burning rice husks at temperatures up to 750 C. The main component in RHA is silica oxide, generally ranging from 80 to 95%, depending on the unburnt carbon content (Bui, 2001). RHA usually contains a relatively high amount of unburnt carbon depending on the production conditions (Yu and Shoya, 1999). However, the reactivity of RHA is not diminshed by the presence of carbon. Tridimite and criestobalite can occur in RHA as a result of conversation of the amorphous silica, depending on the temperature and the duration of the burning process, as well as on the cooling conditions. The pozzolanic activity of RHA is due to the amorphous state of the SiO_2. Because of low soda, potash, and phosphate contents in the RHA, it can be used as a high quality mineral admixture by the cement and concrete industry.

2.2.2 Inert Materials

2.2.2.1 Recycled Concrete

The concept of sustainable development in construction has been gaining increasing attention at the present time (WRAP, 2008). The most immediate and obvious way to achieve more sustainable construction is by conserving new raw materials such as natural aggregates, and reusing construction and industrial wastes. Recycled concrete aggregate (RCA) is an example of a common construction waste that is produced from demolishing concrete structures as they approach the end of their service life. Supplementary cementing materials (SCM) such as fly ash and slag are industrial by-products, which have a long history of use with Portland cement (PC) in concrete.

In terms of using RCA in structural concrete, research has shown that the use of 30% RCA and 70% natural aggregate in high strength concrete produces concrete of similar strength as that containing only natural aggregates. However, concrete mixtures made with laboratory crushed RCA as the only source of aggregate show a strength reduction of 10% when compared to conventional concrete (Rahal K., 2005). For some types of commercially crushed RCA, research has shown negligible variation from concrete made from virgin materials in terms of compressive and tensile strength (Sagoe- Crentsil KK et al, 2005). However, drying shrinkage is of concern when using RCA in concrete. New concrete made with RCA experiences creep and drying shrinkage that is 10– 30% greater than that of concrete made from natural aggregate (Ramachandran,1981) . The high porosity of RCA increases drying shrinkage (Sagoe-Crentsil KK et al; 2001) and creep especially when fine RCA is used. In addition, RCA generally has a lower elastic modulus than natural aggregate, which also contributes to drying shrinkage and creep. Fine RCA has been found to have limited use in structural concrete as it is angular and coarser than natural aggregate which affects the workability and ease of finishing. In addition, fine RCA was found to reduce the resistance to freezing and thawing (Zaharieva R et al,2004) and sulphate attack when used with PC of 10.1% C_3A (Lee ST et al, 2005).

Research showed substantial improvement in the properties of concrete containing RCA when the fine portion was replaced by natural sand; other research work suggested limiting the fine RCA content in concrete to 30% or 50% (US department of Transportation, 2004) of the fine aggregate content in the mix. From the sustainability standpoint, and based on the above review, it is important to develop more construction materials that incorporate RCA. This is of special importance for fine RCA and low-quality coarse RCA, which have limited use in structural concrete. Finding more uses of RCA helps reduce its disposal in landfills and conserves the consumption of natural aggregates.

2.2.2.2 Recycled Construction Demolish

The inert fraction or ‘‘core” construction and demolition waste (C&DW), which is essentially the mix of materials obtained when an item of civil engineering infrastructure is demolished, i.e., the fraction derived from concrete, bricks and tiles, is well suited to being crushed and recycled as a substitute for newly quarried (primary) aggregates. Although there are many potential uses for recycled demolition aggregate, most are currently used for low value purposes such as road sub-base construction, engineering fill, or landfill engineering (Soutsos MN et al, 2004). Increase research and development to improve the quality of recycled demolition aggregate. Demonstrate where recycled demolition aggregates are competitive with newly quarried ones. Confidence could be built by identifying, undertaking and monitoring appropriate demonstration projects and disseminating the results. Expand specifications to accept more recycled demolition aggregate where it has been shown to compete technically. Performance criteria for the finished product are preferable to ‘‘recipe” based specifications if recycled demolition aggregate is to be used more widely. (Rahal K, 2007)

2.2.2.3 Scrap Tyies

Many authors have reported the properties of concrete with used tyre rubbers. Their results indicate that the size, proportion, and surface texture of rubber particles affect the strength of used tyre rubber contained in concrete (Eldin NN, Senouci AB,1993) conducted experiments to examine the strength and toughness properties of rubberised concrete mixtures.

They used two types of tyre rubber, with different tyre rubber content. Their results indicated approximately 85% reduction in compressive strength, whereas the splitting tensile strength reduced by about 50% when the coarse aggregate was fully replaced by chipped tyre rubber.

A smaller reduction in compressive strength (65%) was observed when sand was fully replaced by fine crumb rubber. Concrete containing rubber did not exhibit brittle failure under compression or splitting tension and had the ability to absorb a large amount of energy under compressive and tensile loads. A more in-depth analysis of their results indicates an optimized mixture proportion is needed to optimize the tyre rubber content in the mixture. Biel and Lee had used recycled tyre in concrete mixtures made with magnesium oxychloride cement, where aggregate was replaced by fine crumb rubber up to 25% by volume (Biel TD, Lee H. 1996) . Their results of compressive and tensile strength indicated that there is better bonding when magnesium oxychloride cement is used. They discovered that structural applications could be possible if the rubber content is limited to 17% by volume of the aggregate (Schimizze et al. 1994) developed two rubberised concrete mixtures using fine rubber crumbs in one mixture and coarse chipped rubber in the second. While these two mixtures were not optimized and their mixture proportioning parameters were selected arbitrarily, their results indicated a reduction in compressive strength of about 50% with respect to the control mixture. The elastic modulus of the mixture containing coarse chipped rubber was reduced by about 72% of that of the control mixture, whereas the mixture containing the fine rubber crumbs showed a reduction in the elastic modulus by about 47% of that of the control mixture. The reduction in elastic modulus indicates higher flexibility, which may be viewed as a positive gain in mixtures used in stabilized base layers in flexible pavements. In recent years, used tyre chipped rubber containing Portland cement concrete for uses in sound/crash barriers, retaining structures, and pavement structures has been extensively test results showed that the introduction of used tyre chipped rubber considerably increases toughness, impact resistance, and plastic deformation but in almost all cases a considerable decrease in strength was observed. Khatib and Bayomy studied the influence of adding two kinds of rubber, crumb (very fine to be replaced for sand) and chipped (at the size of 10–50 mm to be replaced for gravel

(Khatib ZK and Bayomy FM, 2005). They made three groups of concrete mixtures. In group A, crumb rubber to replace fines, in group B, chipped rubber to replace coarse aggregate, and in group C both types of rubber were used in equal volumes.

In all, the three groups had eight different rubber contents in the range of 5–100% were used. They found that the compressive strength of concrete would decrease with increasing rubber content. For example, replacing 100% gravels by chipped rubber would decrease the compressive strength of concrete up to 90%. Mean- while, they showed that the rubberized concrete made with chipped rubber has less strength than concrete made with crumb rubber. Topcu investigated the particle size and content of tyre rubbers on the mechanical properties of concrete. He found that, although the strength was reduced, the plastic capacity was enhanced significantly. (Topcu, 1995).

Li G. et al. (2004) tried to improve the strength and stiffness of used tyre modified concrete by using larger sized (approximately 25, 50, and 75 mm long and 5 mm thick) chipped rubber fibres and NaOH treating. They concluded that such fibre rubbers perform better than chipped rubbers (approximately 25 x 25 mm square shaped with 5 mm thickness) do but the NaOH surface treatment does not work for larger sized chipped tyres. Researchers found that the dynamic modulus of elasticity and rigidity decreased with an increase in the rubber content, indicating a less stiff and less brittle material. Also the impact resistance of concrete increased when rubber aggregate were incorporated into the concrete mixtures. The increase in resistance was derived from the enhanced ability of the material to absorb energy. (Khatib ZK, Bayomy FM, 1999) From the above literature survey, it is seen that used tyre-rubber concrete is characterized as having high toughness but low strength and stiffness. By comparing and contrasting these studies, it is clear that these differences in their results are due to the quality of gravel materials and cement, as well as various procedures used for attaining to concrete mixture proportions. Meanwhile, in all of these studies, replacing gravel had been done by volume percentage. In the research program reported in this paper, to review the influence of using used rubber, the percent replacement by weight was considered for replacing the Standard Iranian coarse aggregate. Various mixtures were proportioned and mechanical tests were performed.

2.2.2.4 Recycled Plastics

Plastics have become an inseparable and integral part of our lives. The amount of plastics consumed annually has been growing steadily. Its low density, strength, user-friendly designs, fabrication capabilities, long life, light weight, and low cost are the factors behind such phenomenal growth. Plastics have been used in packaging, automotive and industrial applications, medical delivery systems, artificial implants, other healthcare applications, water desalination, land/soil conservation, flood prevention, preservation and distribution of food, housing, communication materials, security systems, and other uses. With such large and varying applications, plastics contribute to an ever increasing volume in the solid waste stream. In the year 1996, plastics amounted to about 12% of MSW, by weight, in United States (Franklin Associates Ltd., 1998). The waste plastics collected from the solid wastes stream is a contaminated, assorted mixture of plastics. This makes the identification, segregation, and purification of the various types of plastics very challenging. In the plastics waste stream, polyethylene forms the largest fraction, which is followed by PET.

2.2.2.5 Polyethylene Terephthalate (PET)

PET is a kind of polyesters made of the ethylene glycol and terephtalic acid's composition and its chemical name is Polyethylene Terephthalate or ‘‘PET’’. PET is one of the most widely used plastics in the package industry because of high stability, high pressure tolerance, non-reactivity with substances and great quality of gas trapping which can preserve the gas in the gaseous drinks. In 2009, Nopcor (National Association of PET Container Resources) found that the overall amount of recyclable PET bottles and glasses in the United States was about 2.34×10^{9} kg in 1 year, whereas the recycled quantity was just about 6.53×10^{8} kg which is 28% of the existing amount (National association, 2009). There are different methods for disposing such materials: burial, incinerate and recycling (Williams PT, 1998). It is possible to benefit from the produced heat during incineration, but the combustion of some kinds of wastes like PET bottles may produce poisonous gasses. Another problem arises from the fact that these materials slowly decompose and they need hundreds of years to return to the cycle of nature.

So it seems that recycling is the best way because of environmental compatibility and economic benefits (Albano C et al, 2009)

Recycling PET waste bottles as PET fibers to make fiber reinforced concrete has been considered in many researches (Foti D , 2011). The volume of fiber content with respect to fiber concrete is between 0.3% and 1.5%. So, this procedure recycles small amount of plastic PET wastes. The most economical way is using PET particles as a substitute of aggregates and mortar. As a result, using PET waste as an aggregate in concrete has some benefits such as decreasing the usage of natural resources, the wastes consumption, preventing the environmental pollution and economizing energy (Kim SB et al, 2010). Frigione studied substitution of 5% of fine aggregate with the same weight of PET aggregates which are made from un- washed PET bottle wastes. The results show that unwashed PET with the 300 kg/m^3–400 kg/m^3 cement content and 0.45–0.55 water to cement (w/c) ratios has approximately the same slump as the ordinary fresh concrete. In addition, compressive and tensile strength of this kind of concrete are slightly lower than the reference sample, while it has smaller modulus of elasticity; which is equivalent to more plasticity. (Frigione, 2010) Albano investigated the mechanical behavior of the PET waste particles in which, the volume substitution ratios were 10% and 20% and the average PET particle size were about 0.26 cm and 1.14 cm. The results show decrease in compressive strength, tensile strength and modulus of elasticity. Adding PET to the concrete mixture leads to decrease in concrete rigidity; which is useful when flexibility of the material is needed. According to non-destructive tests, adding PET particles to the concrete mixture results in reduction of slump, increase of water absorptions, and also reduction in propagation rate of ultrasonic pulse. (Albano et al. 2009) Chio et al. (2009) studied substitution of sand with PET aggregates which were made of PET particles and stone powder and they reported a decrease in concrete unit weight and an increase in water absorption.

The results also show that as the substitution percentage increases, the flow value increases as well; and the reason is the round and slippery surface of PET aggregates that decreases the friction between the mortar and the aggregates. In addition, this replacement has reduced the compressive strength.

Akçaozoglu et al. (2010) examined the effect of PET waste particles as aggregate on two groups of mortars. One of them was entirely made of PET aggregates and the other one was made of both sand and PET aggregates.

The results show that the unit weight, compressive strength and tensile–flexural strength of the mortars including PET aggregates are less than the mortars contain combination of both sand and PET aggregates. Both mortars had much lower unit weight, compressive strength and tensile–flexural strength compared with reference sample mortars.

Marzouk et al. (2007) used PET waste particles with maximum size of 5 mm as aggregates in concrete. The results indicated that when the amount of PET aggregates increases from 0% to 5%, the strength of samples slightly decreases. Besides, if the amount of re- placed PET aggregates exceeds 50%, the mechanical characteristics of the samples will intensely decrease.

Reis et al. (2011) replaced different weight ratios of sand (5%, 10%, 15% and 20%) with the same weight of plastic PET and analyzed the fracture strength of these composites. The results show that weights of the samples which were containing polymeric materials were reduced. Their flexural behaviors were significantly improved and the energy absorption was increased. Furthermore, the results indicated that the probability of brittle failure mode of the samples was diminished. Hannawi et al.,(2010) used recycled polycarbonate (PC) and PET materials in concrete. Scanning electron microscopy (SEM) analysis in this type of concrete showed a weak cohesion among plastic aggregates and the texture. They also reported lower modulus of elasticity and compressive strength for mortars with increase in the amount of PET particles. This fact made the samples more flexible, so, they can with stand the loads for some time after the failure without collapse. Besides, this study illustrates that replacing some percentage of sand with these plastic particles not only improves the flexural strength and the toughness factor, but also causes these composite to absorb more energy. This characteristic is so much interesting for lots of civil engineering applications such as structures subjected to dynamic and impact loads.

Foti , (2011) analyzed the reinforced concrete with PET bottles waste fibers and found that adding little amount of recycled fibers from PET bottle wastes can have a great influence on post-cracking performance of simple concrete elements. As well, these fibers improve the toughness of samples and increase the plasticity of concrete. Oliveira et al. (2011), used fibers made from recycled PET bottles in reinforced mortar. They added different volumes of fiber with the variable quantity of 0%, 0.5%, 1%, and 1.5% to the dry mortars. Their results showed that using PET fibers makes a significant improvement on compressive strength of mortars, in addition to a notice- able effect on their flexural strength along with increase in their toughness.

2.3 Self Compacting Concrete

Self-compacting concrete (SCC) has emerged in Japan in the late 1980s as a material that can flow under its own weight, completely filling formwork, and achieving full compaction, even in the presence of congested reinforcement. The hardened concrete is dense, homogenous and has the same engineering properties and durability as traditional concrete (Nehdi et al., 2004). The purpose of SCC concept is to decrease the risk due to the human factor, to enable economic efficiency, less human work, more freedom to designers and constructors, to lower noise level on the construction site. The common practice to produce SCC is to limit the coarse aggregate content associated with its maximum size and to use the lower water-binder ratios together with appropriate superplasticizers (Okamura and Ozawa, 1995).

In order to achieve a SCC of high fluidity and to prevent the segregation and bleeding during transportation and placing, the formulators have employed a high volume of Portland cement and chemical admixtures (Lachemi et al., 2004). In some cases, the saving in labor cost might offset the increased cost. But the use of mineral admixtures such as fly ash, ground granulated blast furnace slag, marble powder, limestone filler, etc. reduced the material cost of the self –compacting concretes and also improved fresh and hardened properties of the concretes. Using mineral admixtures especially in SCC necessitates further attention. On incorporation of such materials, certain properties of the concretes may be enhanced whereas others may worsen relative to the plain Portland cement concrete.

2.3.1 Fresh properties of SCC

2.3.2 Rheology of SCC

The rheological properties of concrete are important for the construction industry because concrete is usually put into place in its plastic form. Characteristic phenomena of liquid and gas to immediately deform when subjected to small shearing stress is called ‘‘flow’’. The study of flow process that deals with relations between stress and strain and their time dependent derivative is called ‘’rheology’’ (Ozawa et al., 1989). In practice, rheology is concerned with materials whose flow properties are more complicated then of a simple fluid or ideal elastic solid (Tattersall et al., 1983). Without any vibration, concrete is viscoplastic. To make it flow, strong shearing forces are necessary to break the bonds between grains, and that is where the initial yield value of concrete originates form. The vibration process periodically breaks the bonds, and tends to decrease the initial yield value. Whether the floe is facilitated by local shear or vibration, the apparent viscosity is decreased. The admixtures which are called the superplasticizers cause an important decrease in initial yield value without any external mechanical action (Bouzoubaa et al., 2001). The rheological properties of fresh concrete are determined by the so-called rheometers which measure the shear stress at varying shear rates. Unfortunately the inherent properties of concrete make it impossible to use the rheometers designed for neat fluids without any solid particles. Therefore, there isn’t a consensus on the rheological properties of SCC that are available in the market (NIST, 1999). In a comprehensive study by NIST, a series of twelve concrete mixtures was tested by five rheometers.

The mixtures had slumps ranging from 90 mm to 235 mm, but more importantly, they had a wide range of combinations of yield stress and plastic viscosity. It was found that the rheometers gave different values of the Bingham constants of yield stress and plastic viscosity, even for those instruments that give these directly in fundamental units (NIST, 1999).

Compared to conventional concrete, SCC exhibits:

Significantly lower yield stress (near zero): allows concrete to flow under its own mass.

Similar plastic viscosity: ensures segregation resistance

Plastic viscosity must not be too high or too low;

Too high: concrete is sticky and difficult to pump and place

Too low: concrete is susceptible to segregation .

2.2.3 Workability Requirements of SCC

Workability is defined in terms of the amount of mechanical work, or energy, required to produce full compaction of the concrete without segregation. Because of the high content of powder, SCC may show more plastic shrinkage or creep than ordinary concrete mixes. These aspects should therefore be considered during designing and specifying SCC. The workability of SCC is higher than the highest class of consistence described within EN 206 and can be characterized by the following properties (EFNARC, 2002):

- Filling ability

- Passing ability

- Segregation resistance

Filling ability: SCC must flow freely under its own weight, both horizontally and vertically, and to completely fill every corner of the formwork without leaving voids.

Passing ability: SCC must flow freely between the congested reinforcement bars and cover reinforcement without segregating, and without having the need of applying any external forces like vibrator.

Segregation resistance: SCC must keep homogeneity while flowing and during placement. There should be no separation of aggregate from paste or water from solids, and no tendency for coarse aggregate to sink downwards through the fresh concrete mass under gravity (EFNARC, 2005). If the expected workability requirements have been achieved from the produced concretes, the following most important advantages can be obtained (Okamura, 1999):

- Faster construction
- Reduction in site manpower
- Easier placing
- Improved durability
- Thinner concrete sections
- Greater freedom in design
- Better surface finishes
- Reduce noise levels, absence of vibration
- Safer working environment

Table 2.1: List of test methods for workability properties of SCC (EFNARC, 2002)

No	Method	Property
1	Slump Flow by Abrams Cone	Filling ability
2	T_{50} Time Slump Flow	Filling ability
3	J – Ring	Passing ability
4	V - Funnel	Filling ability
5	V- Funnel and $T_{5\ minutes}$	Segregation resistance
6	L - Box	Passing ability
7	U - Box	Passing ability
8	Fill - Box	Passing ability
9	GTM Screen Stability Test	Segregation resistance
10	Oriment	Filling ability

2.3.2 Hardened properties of SCC

2.2.1. Compressive Strength

The compressive strength of concrete is the most important of all the mechanical properties. Measuring compressive strength is influenced by many factors including specimen size, curing conditions, load rate, etc. In order to control variations in testing and consequently variations in results, a standard test method was developed by ASTM International. The standard for determining the compressive strength of concrete is outlined in ASTM C 39–11, “Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.” This standard requires cylindrical specimens for testing. The specimens used in laboratory testing measure either 4 in. (102 mm) in diameter x 8 in. (203 mm) in height or 6 in. (152 mm) in diameter x 12 in. (305 mm) in height. The specimens are prepared by filling the molds in equal lifts and rodding each lift a specified number of times. The numbers of lifts and extent of rodding depends on the diameter and cross sectional area, which is specified in ASTM C 192-07 “Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory.”

After each lift, the mold is also stuck with a mallet to ensure consolidation. After 24 hours in a moist curing chamber, the specimens are de-molded and returned to the moist curing chamber until the proper test date. Common testing dates for measuring a concrete’s strength gain profile are 1, 7, and 28 days after batching. The cylindrical specimens are ground flat or capped before testing. This flat surface reduces localized stress on the specimen. Capping can be done with sulfur capping compound or neoprene pads. Dimensions of the specimens are taken before being loaded at a constant rate until E-11 failure. The load recorded at failure is divided by the cross-sectional area to find the compressive strength of the concrete.

2.2.2. Modulus of Elasticity

Due to the nonlinear inelastic behavior of concrete, the modulus of elasticity (MOE) can be different depending on how it is measured. The MOE is the slope of the stress–strain curve between two designated points. An example of the different moduli of elasticity that can be measured can be seen in Figure 2.1.

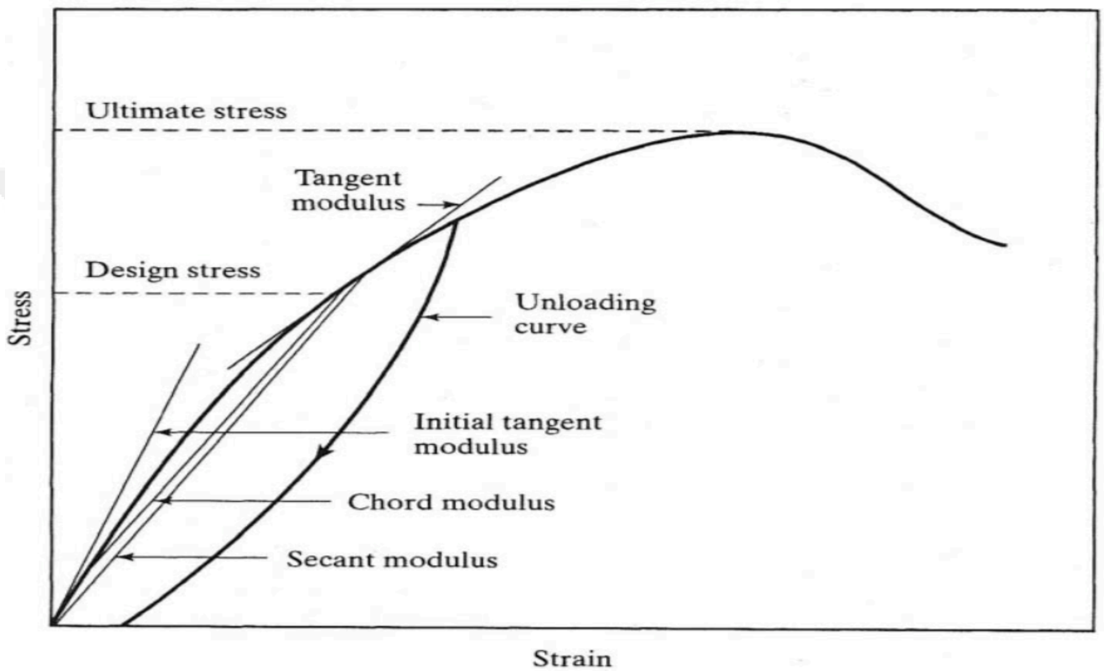

Figure 2.1: – Typical Stress-Strain Diagram for Concrete, Showing the Different Elastic Moduli [Mindess et al., 2002]

In order to standardize the measured modulus of elasticity, ASTM International developed a standard test method ASTM C 469-10, "Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression." This test method measures what is known as the chord modulus of elasticity. The specimens used in this test are the same type used in the compressive strength test. Either the 4 in. (102 mm) or 6 in. (152 mm) diameter cylindrical specimens can be used. Specimens are fabricated and cured in the same manner as the compressive strength specimens. After 28 days of moist curing, specimens are prepared for testing. Using a compressometer, the strain produced at 40% of the ultimate load is recorded. Also, the stress that produces a measured strain of 0.00005 in./in. is recorded.

Using these values, the chord modulus of elasticity can be calculated in accordance with Eq. 2.1:

$$E_C = \frac{(S_2 - S_1)}{(\varepsilon_2 - 0.00005)}$$

2.2.3. Modulus of Rupture

The modulus of rupture is an important property in the calculation of the cracking moment of concrete and thus determining how a concrete member will behave post-cracking. ASTM International has created a standard for testing the modulus of rupture known as ASTM C 78-10, "Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)." This approach is an indirect way to measure the tensile strength of concrete.

The specimen has to have an overall depth of a third of the span length. The span length shall be such that it measures three times the distance in between the load points of the testing apparatus. Also, the specimen shall overhang the supports by at least 1 in. (25 mm). The schematic diagram in Figure 2.2 summarizes these requirements.

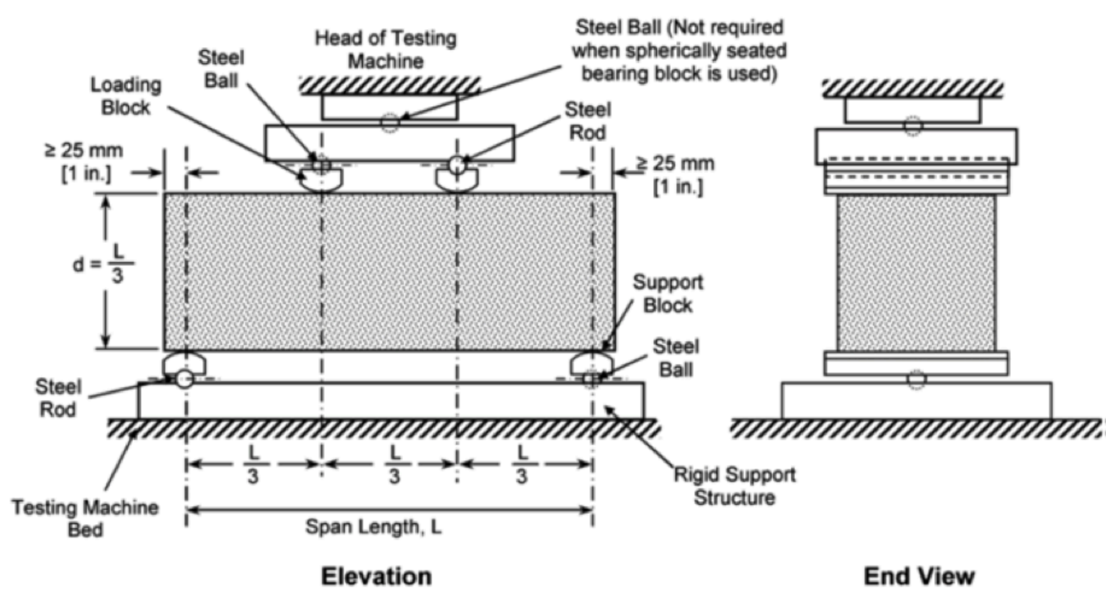

Figure 2.2: Schematic Diagram

The specimen is then loaded until failure. After testing, the dimensions are recorded and the modulus of rupture is computed in accordance with Eq. 2.2. While this test method overestimates the "true" tensile strength of concrete, the test does simulate the most common way concrete is placed into tension, through flexure.

Eq. 2.2:

$$R = \frac{PL}{bd^2}$$

2.2.4. Splitting Tensile Strength

Tensile strength test is outlined in ASTM C 496–11, "Splitting Tensile Strength of Cylindrical Concrete Specimens." The cylindrical specimens measure either 4 in. (102 mm) in diameter by 8 in. (203 mm) in height or 6 in. (152 mm) in diameter and 12 in. (305 mm) in height. The method for preparing the specimens used in the splitting-tensile test is outline in ASTM C 192. Specimens are E-14 stored in a moist curing chamber and tested after 28 days. Diameteral lines are drawn on the specimens to ensure that they are in the same axial plane. The dimensions of the specimens are then taken.

The specimens are then placed on top of a 1 in. (25 mm) wide x 3/8 in. (10 mm) thick plywood strip within the testing apparatus. A second plywood strip is then placed on top of the specimen so the two strips align with the diametral lines. This ensures that the load is distributed in one plane of the specimen. The peak load is recorded and the tensile strength is then calculated in accordance with Eq. 2.3

Eq. 2.3:

$$T = \frac{2P}{\pi LD}$$

CHAPTER 3

EXPERIMENTAL STUDY

In this thesis, experimental program was conducted to investigate the properties of the self-compacting concretes made with waste granular polyethylene terephthalate (PET). In the first stage, waste granular polyethylene terephthalate (PET) were obtained from plastic recycling plant. PET particles were aimed to be utilized fine aggregate replacement in concrete. The slump flow diameter, slump flow time, V-funnel time tests were carried out to identify the required properties and the characteristics of fresh SCC mixes. The concretes were also tested for the mechanical, physical, and durability properties. The hardened concretes were tested for the compressive strength, splitting tensile strength at 28 days for the evaluation of mechanical properties. Apart from those, the durability related permeability tests were conducted to investigate the water sorptivity, water absorption of SCCs at the age of 28 days.

3.1 Materials

3.1.1 Cement

The cement used in all mixtures was a normal portland cement CEM-I 42.5 R, which conforms to TS EN 197-1 (2002). It was obtained from Limak Gaziantep Cement Factory.

Table 3.1: Chemical composition and some physical properties of the cement used in the study

Chemical Analysis (%)	Portland Cement
CaO (%)	63.60
SiO_2 (%)	19.49
Al_2O_3 (%)	4.54
Fe_2O_3 (%)	3.38
MgO (%)	2.63
SO_3 (%)	2.84
K_2O (%)	0.58
Na_2O (%)	0.13
LOI (Loss of Ignition) (%)	2.99
Specific Gravity	3.13
Blanine Fineness (cm^2/g)	3280

3.1.2 Aggregates

The coarse aggregate used was river gravel with a nominal particle size of 16 mm in order to avoid the blocking effect of aggregate. As fine aggregate, the mixture of natural river sand and crushed stone was used with a nominal particle size of 5 mm.

The particle size gradation obtained through the sieve analysis and physical properties of the fine and coarse aggregates are presented in Table 3.2. Aggregate grading curve and the zones are given in Figure 3.1.

Table 3.2: Sieve analysis and physical properties of the fine and coarse aggregates

Sieve Size (mm)	Coarse	Natural sand	Crushed Sand
16	100	100	100
8	59	100	100
4	5	83	92
2	2	58	67
1	1	42	45
0.5	1	25	24
0.25	0.6	6	9.3
Fineness Modulus	5.32	2.87	2.63
Specific gravity	2.74	2.65	2.41

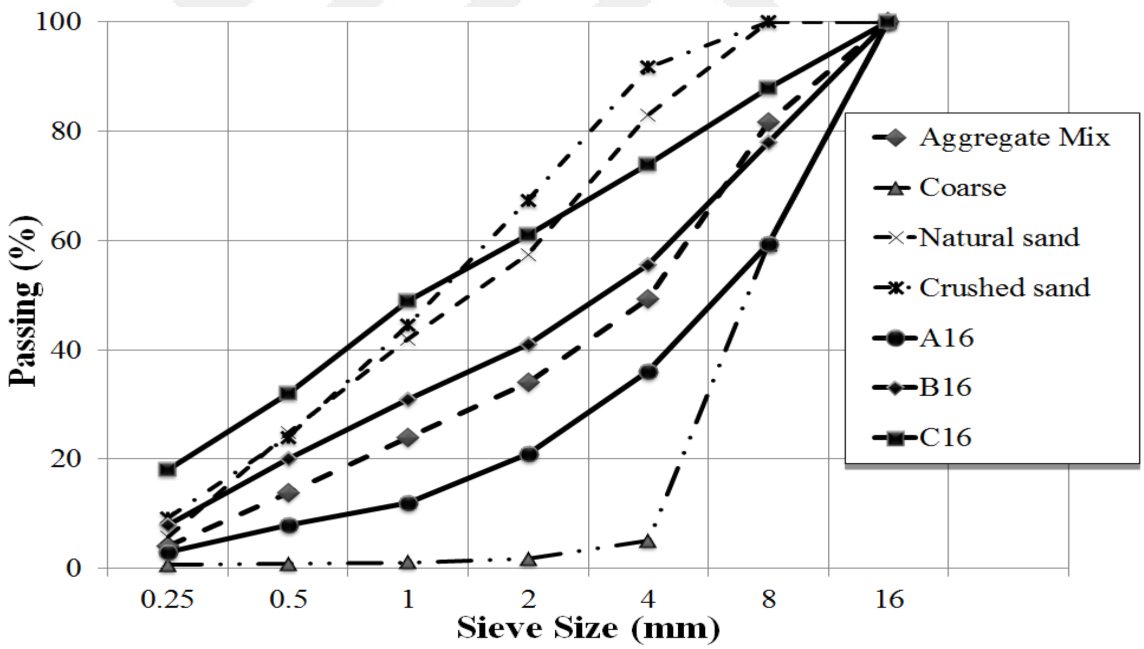

Figure 3.1: Grading curves of the aggregates used and standard reference curves

3.1.3 Super plasticizer

A polycarboxylic-ether type superplasticizer (SP) with a specific gravity of 1.07 and pH of 5.7 was used in all mixtures. The properties of superplasticizer are given in Table 3.3 as reported by the local supplier.

Table 3.3: Properties of superplasticizer

Properties	Superplasticizer
Name	Glenium 51
Color Tone	Dark Brown
State	Liquid
Specific Gravity	1.07
Chemical Description	Modified polycarboxylic type of polymer

3.1.4 PET granules

In order to observe the effect of PET granules on the fresh and hardened properties of SCC PET replaced fine sand with different volume ratios from 0 to 8 %. As it can be observed from Figure 3.2 the shape of PET granules look like elongated fibers. Threfore sieve analysis was not applied. The PET granules were obtained from a local PET crushing plant.

Figure 3.2: Photographic view of PET granules

3.2 Concrete mixtures

Self-compacting concrete mixtures were produced with a constant water/binder ratio of 0.32 and total binder content of 570 kg/m^3. In the production of SCCs, PET granules were replaced the fine sand with an increasing amounts by 1% increment up to 8%. During trials it was observed that for the SCCs having more than 8% of PET granules required too much HRWRA. The concretes were separated into two groups according to the amount of HRWRA. Group 1 (up to 5% replacement level) contained 1.5% HRWRA, while Group 2 (PET6, PET7, and PET8) had 1.6%. The details regarding why the dosage of HRWRA was changed as well as discussion of fresh properties of SCCs are given in the next chapter. Coding of the mixtures was based on the replacement level of PET granules. For example, PET3 means SCC mixture containing 3% PET granules in SCC production. Details of the mix proportions of SCCs are given in Table 3.4.

Table 3.4: Details of mix proportions of SCCs, kg/m^3

Materials	Mixtures								
	PET0	PET1	PET2	PET3	PET4	PET5	PET6	PET7	PET8
Cement	570	570	570	570	570	570	570	570	570
Water	182.4	182.4	182.4	182.4	182.4	182.4	182.4	182.4	182.4
Coarse aggregate	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Medium aggregate	771.9	771.9	771.9	771.9	771.9	771.9	771.9	771.9	771.9
Natural sand	655.3	648.8	642.2	635.7	629.1	622.6	616.0	609.5	602.9
Crushed sand	249.0	246.5	244.0	241.5	239.0	236.5	234.0	231.5	229.0
PET	0.0	4.7	9.5	14.2	18.9	23.7	28.4	33.1	37.9
SP	8.55	8.55	8.55	8.55	8.55	8.55	9.08	9.08	9.08
Unit weight	2436.3	2432.0	2427.7	2423.4	2419.1	2414.8	2410.5	2406.2	2401.9

3.3 Test methods

In the production of SCC, the mixing sequence and duration are so important that the procedure for batching and mixing proposed by Sonebi et al. (2002) was employed to supply the same homogeneity and uniformity in all mixtures. The batching sequence consisted of homogenizing the fine and coarse aggregates for 30 sec in a rotary planetary mixer, then adding about 1/3 of the mixing water into the mixer and continuing to mix for one more minute. Thereafter, the aggregates were left to absorb the water in the mixer for one minute. After cement and mineral additives were added, the mixing was resumed for another minute. Finally, the SP with remaining water was introduced, and the concrete was mixed for 3 min and then left for 1 min rest. Eventually, the concrete was mixed for additional two minutes to complete the mixing sequence.

The concretes were designed to give a slump flow of 70 ± 3 cm which was achieved by using the superplasticizer at varying amounts. For this, trial batches were produced for each mixture till the desired slump flow was obtained by adjusting dosage of superplasticizer by trial-error.

After the mixing procedure was completed, fresh state tests were conducted on the SCC to determine slump flow time and diameter, V Funnel time. Segregation and bleeding were also visually checked during the slump flow test. To determine the mechanical properties of SCC, the compressive strength test at 28 days were conducted. Test specimens were all cast without any compaction and vibration. After casting and surface finishing, all of the specimens were covered with plastic sheet and kept in laboratory for 24 hours.

Then, demoulded and stored in water ($23 \pm 2^{o}C$) for curing until testing day.

3.3.1 Fresh Properties Specimen Preparation

To classify a concrete as self-compacting, the requirements for filling and passing ability as well as segregation resistance must be fulfilled in order to provide ease of flow when unconfined by formwork or reinforcement, and an ability to remain homogeneous in fresh state. It is specified that the filling ability and stability of self-compacting concrete in the fresh state can be defined by four key characteristics namely flowability, viscosity, passing ability, and segregation resistance (EFNARC, 2005). Fresh properties of the concretes were carried out according to the limitations specified by EFNARC as seen in Table 3.5.

Table 3.5: Slump flow, viscosity, and passing ability classes with respect to EFNARC (2005)

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

3.3.1.1 Slump Flow Test

In this study, the slump flow of all the control mix was adjusted to be 75±3 cm whilst the slump flow time (T_{50}) was measured. After determination of a constant amount of superplasticizer PET was replaced fine sand volumetrically until 8%.

The slump flow test was performed according to EFNARC (2005) test methods. To measure the slump flow, an ordinary slump flow cone (EN 12350-2) is filled with self compacting concrete without any compaction and leveling. The cone is lifted and the average diameter of the spreading concrete is measured as shown on the Figure 3.3. The time ($T_{500\ mm}$) recorded for the concrete to reach the 500 mm

Figure 3.3: Measurement of slump flow diameter

3.3.1.2 V-Funnel flow time

The V-funnel flow test for SCC is also was made like described in EFNARC (2005). The flow time is determined in this test. The funnel completely filled with fresh SCC without any compacting or tamping, and the flow time (t) is measured as the time between the opening of bottom outlet and complete emptying of the funnel that light is seen from above through the funnel.

3.3.2 Hardened Properties

3.3.2.1 Compressive strength

For compressive strength measurement of SCCs, cubical samples of 150 mm were tested in accordance with ASTM C 39 (2012). The test is conducted on three cube samples from each SCC mix at 28 days. The compressive strength was computed by averaging the results from the three tested samples at each testing age.

3.3.2.2 Splitting Strength

According to ASTM 496 (2011), splitting tensile strength of the concrete was measured by using the cylindrical samples of 100x200 mm at 28 days. The splitting tensile strength was obtained by averaging the results from the four tested cylindrical samples.

3.3.2.3 Water absorption

Water absorption is used to determine the amount of water absorbed under specified conditions which indicates the degree of porosity of a material. The water absorption test was conducted by completely immersing dried cube specimens in water at 25 °C for 96 h and noting the amount of water absorbed per unit initial mass in percentage. This gives percentage water absorbed. It was conducted at the age of 28 days.

3.3.2.4 Sorptivity

Water sorptivity was measured on four specimens of 100 mm in diameter and 50 mm in length cut from the of Ø100x200 mm cylinders. Before test, the specimens were dried in an oven at 100±5 °C until they reached the constant mass. The test was conducted on the surface of concrete which is in contact with a thin water layer while the sides of the specimens were covered by paraffin, so that capillary suction was considered the dominant invasion mechanism. Water sorptivity evaluated by the water uptake from the concrete per unit cross-sectional area with time. The test was implemented in 28 days. The schematic presentation of the test set up is shown in the **Figure 3.4** below.

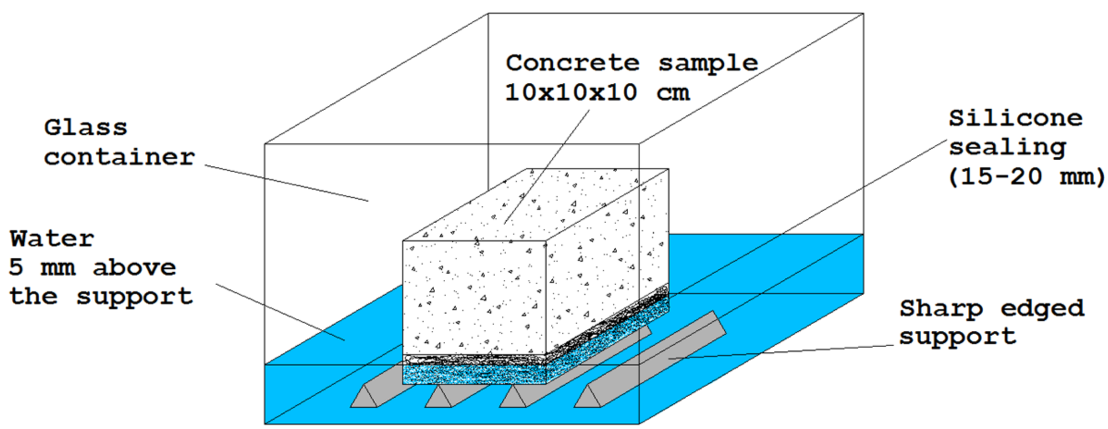

Figure 3.4: Sorptivity test set up

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 Fresh properties

In order to provide a high slump flow diameter for control mixture HRWRA was used as 8.55 kg/m^3 (1.5%). For observation of the effect of addition PET granules, the amount of the chemical admixture was kept constant. However when exceeding 5% replacement level of PET the slump flow diameter decreased dramatically. Therefore, the amount of HRWRA was increased to 1.6% to provide a proper slump flow diameter. The variation of the slump flow diameter and slump flow time is shown in the Figures 4.1 and 4.2 below. Figure 4.1 indicates that increasing the amount of PET granules in resulted in significant reduction in slump flow diameter from 775 mm to 660 mm. Increasing the amount of HRWRA from 1.5% to 1.6% resulted in enhancement in slump flow diameter of the concrete containing 6% PET. The slump flow diameter was measured as 700 mm. However for 7% and 8% PET replacement levels the sharp reduction levels were observed especially for PET8 concrete (535 mm).

Similarly T_{500mm} slump flow time was increased for the SCCs while increasing the PET content. Nevertheless, the tendency of increment is not similar for SCCs with higher than 5% PET content. Figure 4.2 illustrates that while there is a gradual increase in the T_{500mm} time in SCCs up to PET5, significant increase was observed for PET6, PET7 and PET8. The range of T_{500mm} slump flow times for SCCs containing up to 5% PET is 2.93-4.96 sec while for the others 4.17-11.28 sec was observed..

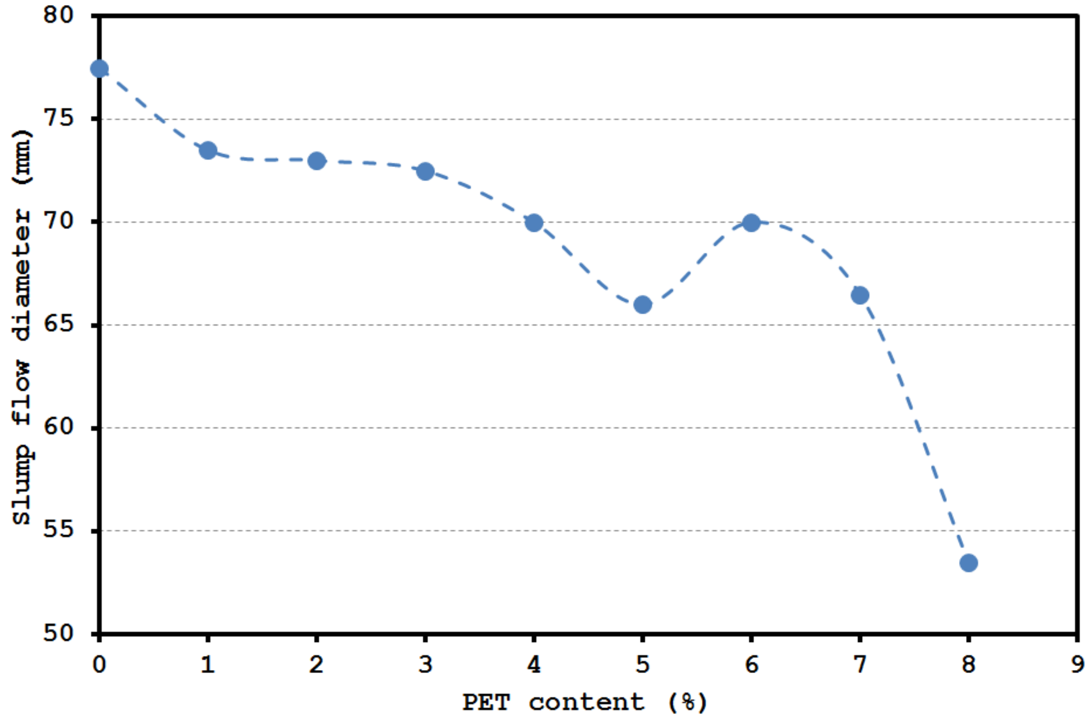

Figure 4.1: Variation of slump flow diameter with PET content

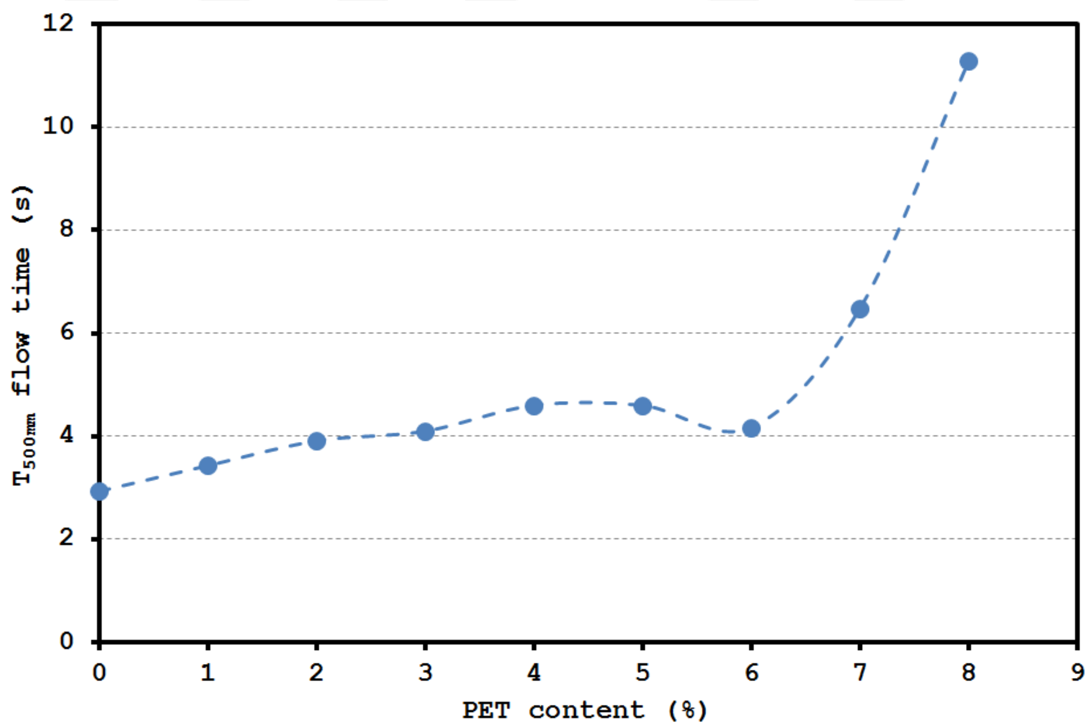

Figure 4.2: Variation of T_{500mm} slump flow time with PET content

V-funnel flow times of the SCCs are shown in the Figure 4.3. The flow times measured for SCCs up to 5% PET remained below 25sec while the values for the other SCCs were above this limiting value. Therefore it can be concluded that the PET replacement level of more than 5% causes the concrete to be more viscous than it can be allowed according to EFNARC (2005) limitations. High viscosity may cause higher friction in the forms and difficulty in consolidation of the concrete.

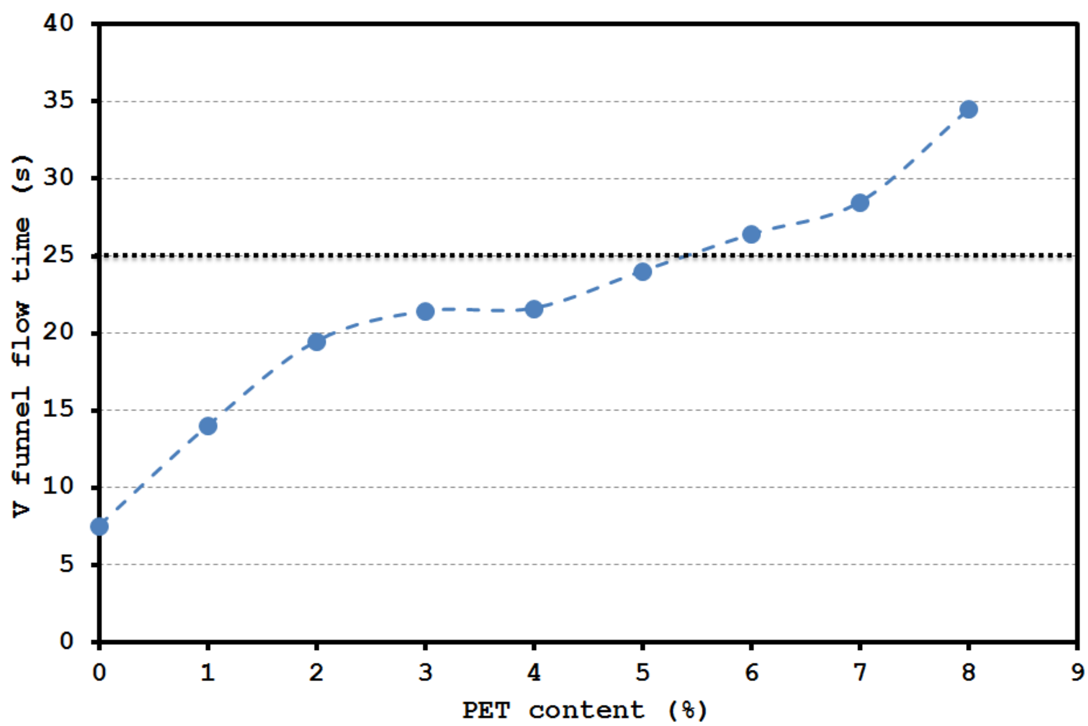

Figure 4.3: Variation of V-funnel flow time with PET content

This behavior can be attributed to the friction characteristics and specific surface area of PET particles. PET particles have more specific surface area compared with the natural sand due to their shape. Hence, there would be more friction between the particles leading to less workability in the mixtures. As the PET content increases, the fresh concrete plasticity and consistency are decreased (Rahmani et al., 2013).

4.2 Hardened Properties

The measured hardened properties of the SCCs produced are mechanical properties in terms of compressive strength and splitting tensile strength and absorption characteristics by total absorption and sorptivity at the end of 28 days of curing. The discussions of the findings are given below.

4.2.1 Compressive and tensile strength

The variation of the compressive strength of the SCCs with increasing the amount of PET granules is given in Figure 4.4. The results indicated that there is a systematic decrease in the compressive strength of concrete as the amount of PET increases. Increasing the amount of PET particles results in weak cohesion between matrix and PET granules as well as acting as a barrier between paste and the aggregate the compressive strength decreases. The figure also illustrated that there is a strong relation between the PET content and the observed compressive strength value.

The test results indicating the splitting tensile strength of the concretes are presented in Figure 4.5 In contrast to compressive strength behavior increasing PET particles up to 5% resulted in slightly improvement of tensile capacity up to 5%. However, exceeding this critical value caused reduction because of high replacement level. In the study of Rahmani et al. (2013) they explain the phenomenon as the increase of the probability of inter locking between the PET particles and fractured surface due to the special shape of PET particles and flexibility. This situation can therefore be attributed to crack arrestment of the PET particles through acting like fiber. However, when exceeding a certain limit as a result of deterioration of the bond between paste and natural aggregate the tensile strength decreased.

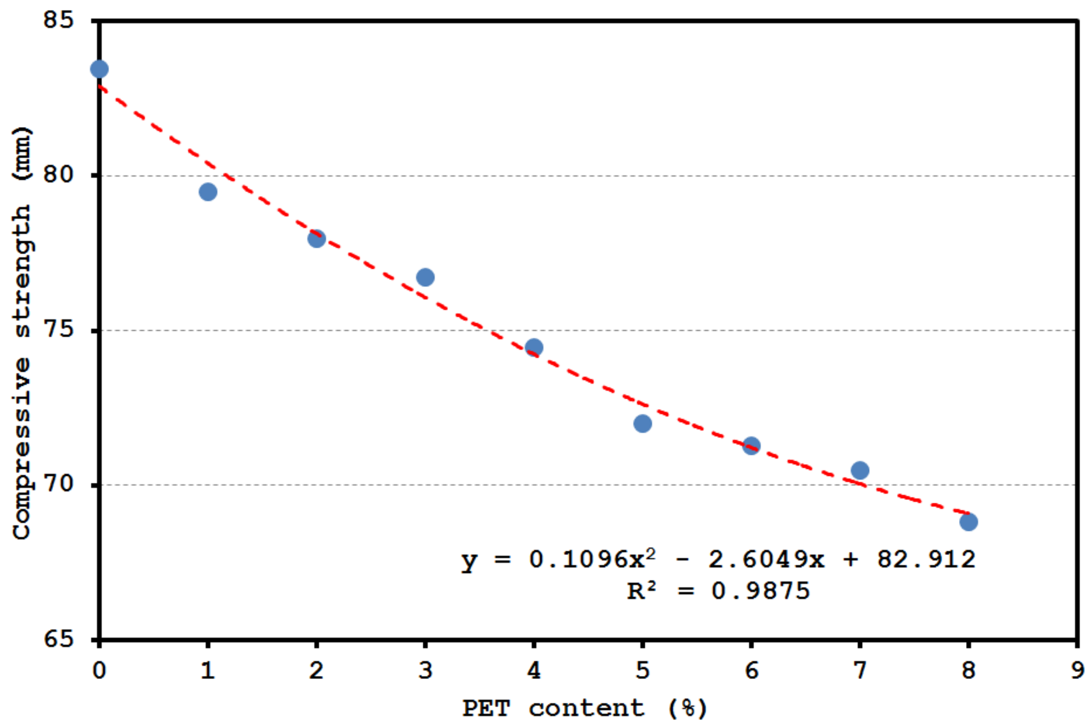

Figure 4.4: Compressive strength of SCCs

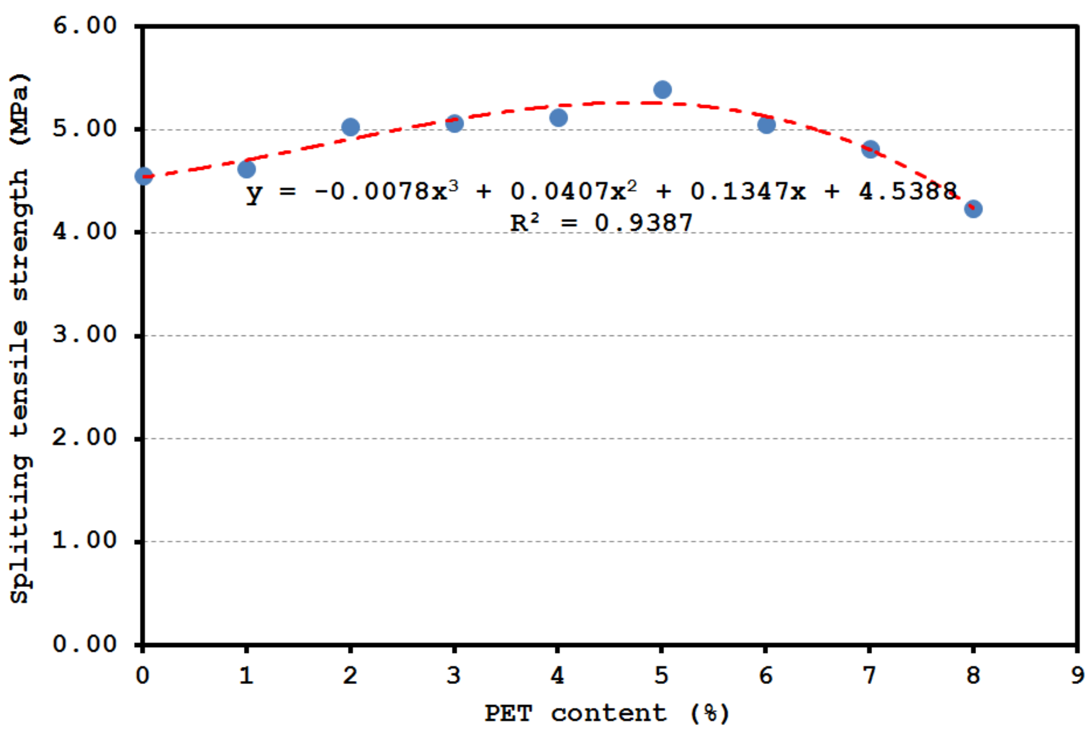

Figure 4.5: Splitting tensile strength of SCCs

Figure 4.6 indicates the relation between compressive strength and splitting tensile strength of the SCCs produced. The correlations indicated that the relation between compressive and splitting strength is irregular. However, when considering a higher order curve fitting, it was found that a parabolic curve with 3rd degree provides a reasonable correlation between these two critical mechanical properties.

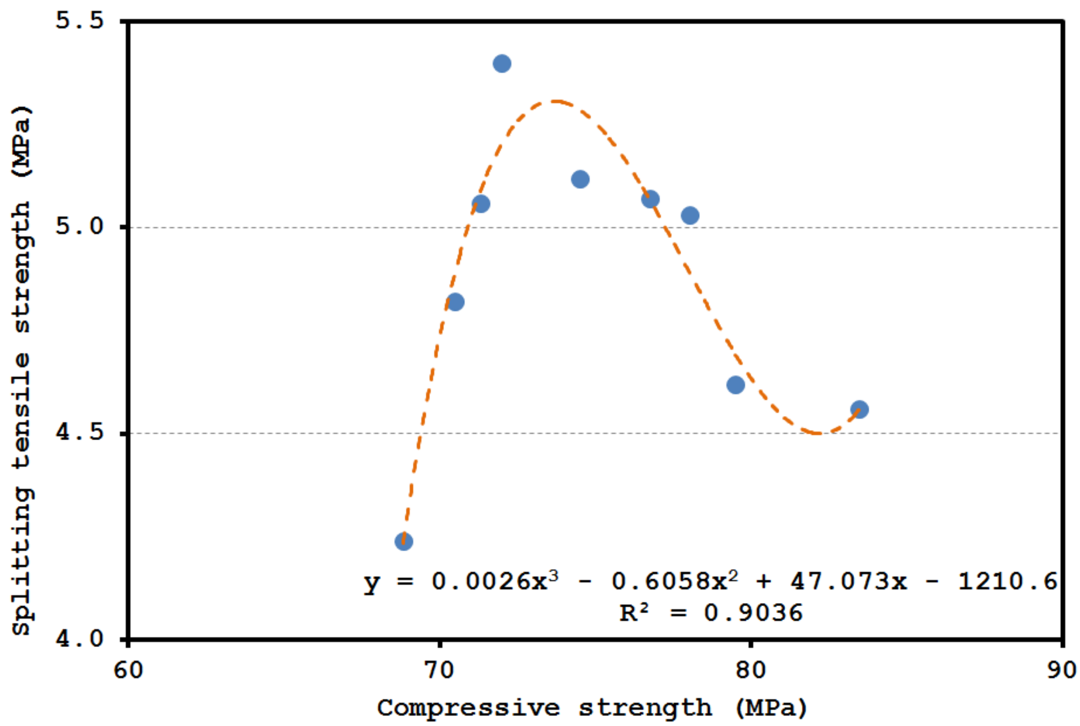

Figure 4.6: Correlation between compressive strength and splitting tensile strength

4.2.2 Water absorption and sorptivity

Water absorption and sorptivity test results of the SCCs versus PET content of the SCCs are exhibited in Figures 4.7-4.8. Figure 4.8 clearly indicates that the porosity of concrete increases as the amount of PET increases the SCCs. The variation of the data proved that there is a good agreement with variation of amount of PET and porosity. Nevertheless, when observing the sorptivity values of the concretes, SCCs with more than 5% PET indicated a decreasing tendency. This can be explained by disturbance of the capillarity of the concrete by the excess amount of PET particles. Therefore it can be inferred that without observing total water absorption of the concrete, tendency of the sorptivity values in this aspect can be misleading to comment on the capillarity of the SCCs.

Figure 4.7 indicates the relation between water absorption and sorptivity of concretes. Since the results of sorptivity and water absorption obtained for PET6, PET7, and PET8 are contradictory, a parabolic curve having 5th order provided a prominent correlation between these properties.

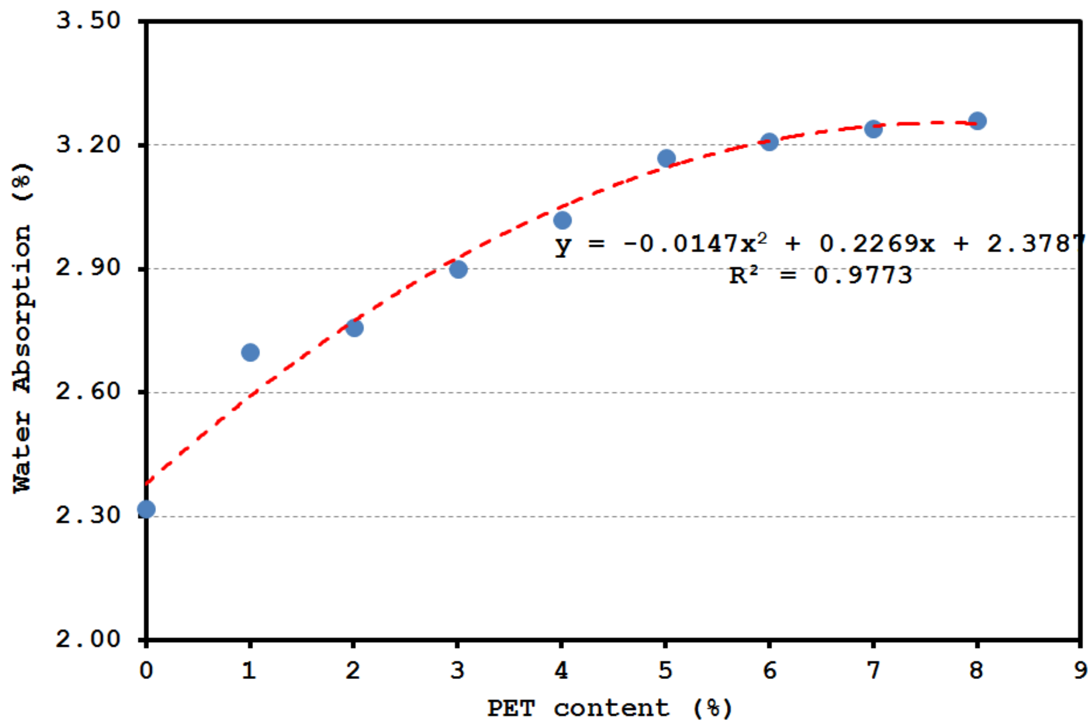

Figure 4.7: Water absorption values of SCCs

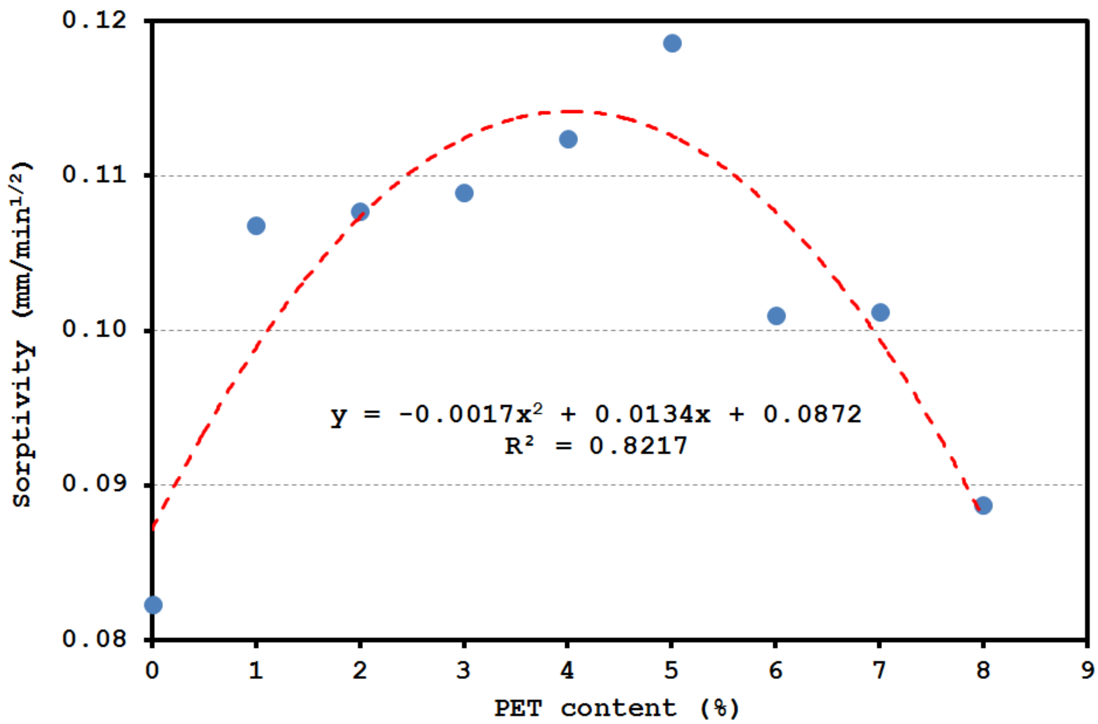

Figure 4.8: Sorptivity indices of SCCs

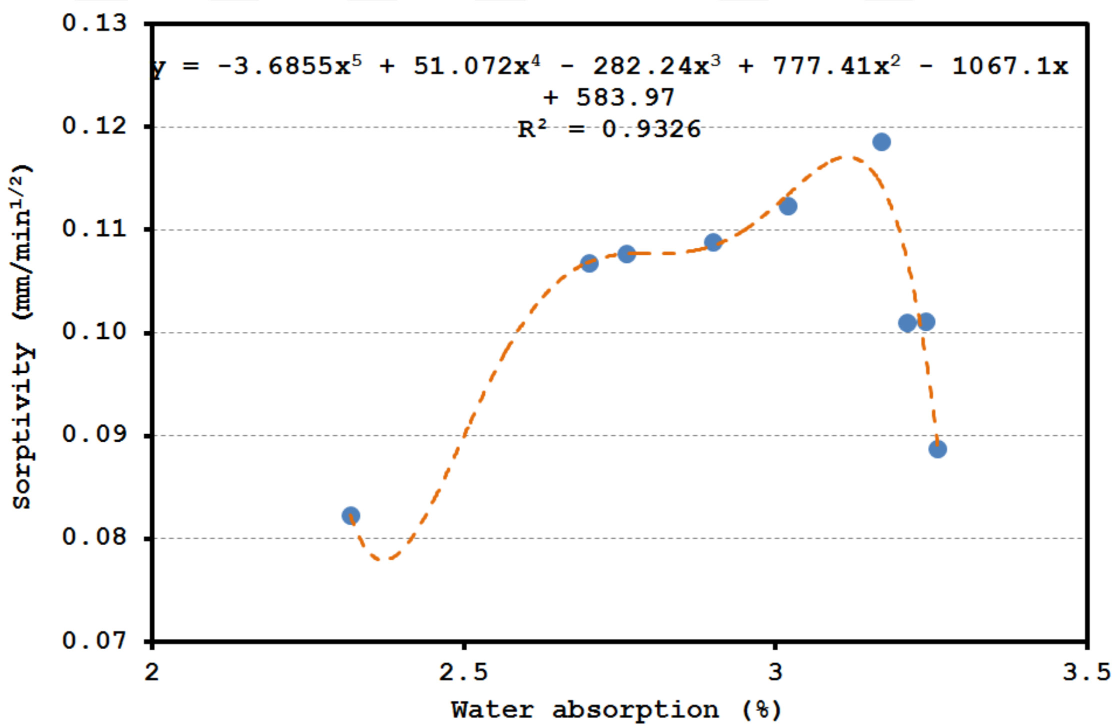

Figure 4.9: Correlation between water absorption and sorptivity of SCCs.

CHAPTER 5
CONCLUSION

In the current study recycled PET granules obtained through crushing of PET bottles or containers were used as a sand replacement material in production of SCC. The following conclusions can be drawn from the experimental study presented herein.

- Utilization of waste PET granules in production of SCC can be an effective way for recycling purpose. However, in order not to get loss of workability the maximum amount of PET replacement level should be limited to 5%. When exceeding 5% of PET content, significant increase in the amount of chemical admixture is required. Moreover, the flow and viscosity behavior of SCC is affected significantly. The results indicated that for PET replacement levels of 6% and higher V-funnel flow time overpassed 25 seconds.
- Inclusion of PET particles in SCC resulted in decrease in the compressive strength. The compressive strength control concrete was 83.4 MPa while PET8 had 68.8 MPa. However, the inclusion of PET particles up to 5% resulted in undistinguishable improvement in the splitting tensile strength capacity. However, beyond this value slight decrease was also observed.
- Being an important indication of pore structure of the concrete, water absorption test result proved that increasing the amount of PET caused occurrence of void in concrete. Since the PET particles are slender and flexible, during casting some particles may be curled to create void inside the concrete. Therefore as the amount of PET increased in SCC water absorption values was increased from 2.3% to 3.3% from PET0 to PET8 respectively.
- The tendency of the deterioration in sorptivity values was similar to water absorption up to 5% of the PET. However, as a result of disturbance of the capillary behavior of the concrete due to the excess amount of PET, reduction in the sorptivity values were observed in SCCs with more than 5% PET.
- Although there was an increase in the water absorption values, due to the mix design parameters assigned for the experimental study, strength and absorption

values of the SCCs produced were still better than conventional concrete. PET5 concrete satisfied all the requirements for SCC with reasonable performance in the hardened properties. The results obtained for this concrete are 72.0 MPa, 5.4 MPa, 3.1%, and 0.1186 mm/min$^{1/2}$ for compressive strength, splitting tensile strength, water absorption, and sorptivity, respectively. Therefore, it can be concluded that by adjusting concrete mix parameters, production of high performance SCC containing 5% PET granules is possible with satisfactory outputs.

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