Effects of Polypropylene Waste Plastic as a Replacement to Coarse Aggregate on Mechanical Behavior of Self Compacting Concrete

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ABSTRACT

In recent years, the usage of recycled plastic aggregates as a replacement to aggregate has been taken into consideration to decrease the environmental effects of both concrete and waste plastics. Recycled plastic aggregate concrete, has come to be recognized as a distinctly promising technology capable of making useful contributions to resource performance in the production industry This thesis outlines an experimental study on the physical and mechanical properties of 0.45 w/b self-compacted concrete (SCC) manufactured using recycled polypropylene (PP) waste plastic as a replacement to natural coarse aggregates. It analyzes the effects of five different percentages (0, 5, 10, 15, 20 and 25%) of PP as a replacement to natural coarse aggregates on compressive strength, flexural strength, splitting tensile strength, workability, weight, ultrasonic pulse velocity and flexural toughness of SCC. It also studies the weight loss, pulse velocity, compressive, splitting and flexural strength changes, when specimens are exposed to two different temperatures as100°C and 200°C.

Experimental results show that; SCC mechanical and physical properties decreased with increased PP percentage up to 25%, because the mechanical and physical properties of SCC concretes, incorporated with PP are lower than those of concretes formed with natural aggregate.

Polypropylene aggregates at high level (25%), has a positive effect on flexural toughness because they were used in small sizes, which could improve flexibility.

Keywords: Self Compacted Concrete, Polypropylene waste plastic, lightweight aggregate, compressive strength, splitting tensile strength, flexural strength, workability, flexural toughness, Heat degradation.

ÖZ

Son yıllarda, atık plastiklerin parçalara ayrıştırılarak agrega yerine kullanılması konusu çok rağbet görmüş olup, hem atık plastiklerin hem de betonun çevreye olan zararlı etkileri azaltılmaya çalışılmaktadır. Atık plastik agrega ile üretilmiş betonlar, teknoloji tarafından kabul görmüş olup, araştırmacılar bu konuya katkı sağlamaya çalışılmaktadır. Bu deneysel çalışmada, s/ç = 0.45 olan, agrega yerine kısmen polipropolin (PP) atık plastik kullanılarak üretilmiş olan kendiliğinden yerleşen beton (KYB)'un fiziksel ve mekanik özelikleri araştırılmıştır.

Agrega yerine betona katılmış olan atık PP parçaları betonun toplam hacminin % (0, 5, 10, 15, 20 and 25%)'i oranlarında betona katılmıştır. Bununla beraber, plastik agrega ile pasta arasındaki bağı arttırmak için karışımlara, çimento miktarının %10'u kadar silis dumanı ve silis dumanı, ve çimento ağırlık toplamının %2.00'si kadar da süperakışkanlaştırıcı (Gelenum 27) katkı kullanılmıştır. Tüm KYB'ların işlenebilirlik tayini için sırasıyla L-kutusu, V-tüneli, ve de akma tablası deneyleri yapılmıştır. Diğer taraftan; akışkanlık ve özgül ağırlık gibi bazı fiziksel özellik tayini, çekme, basınç ve eğilme dayanım, tokluk ve ayrıca 100 °C ve 200 °C sıcaklığa maruz kalmış numunelerde oluşmuş olan dayanıklılık testleri yapılmıştır. Sonuçlardan da belirtildiği gibi gibi, agrega yerine yerleştirilmiş olan atık PP parçalarının %25'ine kadar agrega yerine yerleştirildiği zaman, betonun KYB özelliğini kaybettiği görülmektedir. Diğer yandan, atık PP parçalarının KYB katılmasının işlenebilirlik değişikliğine ve de bazı dayanım kayıplara neden olduğu gözlemlenmiştir. Bunlar, çekme, basınç ve eğilme dayanımları; işlenebilirliğin azalması ve iç çatlakların oluşması durumları olarak verilebilir. Diğer taraftan, atık PP parçalarının KYB'da agrega yerine kullanılmasının;

betonun sünekliğini ve tokluğunu arttırdığı, ağırlığının azaldığı yönlerinden betonda avantaj oluşturduğu anlaşılmıştır.

Anahtar Kelimeler: Kendiliğinden yerleşen beton (KYB), Polypropylene atık plastik, Hafif agrega, Basınç dayanımı, Eğilme dayanımı, Çekme dayanımı, İşlenebilirlik, Tokluk, Isı dayanıklılığı.

DEDICATION

This thesis is dedicated to all my family especially to my parents and my lovely Sisters and Brothers who have been my source of inspiration and support.

I would like to thank
My lovely fiancée who all time encourage me for getting more success.

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LIST OF ABBREVIATIONS

f_c	Compressive Strength
f_f	Flexural Strength
f_t	Splitting tensile strength
PP	Polypropylene
PPWP	Polypropylene Waste Plastic
SCC	Self-Compacting Concrete
SCC0PP	SCC with 0% PP replacement
SCC5PP	SCC with 5% PP replacement
SCC10PP	SCC with 10% PP replacement
SCC15PP	SCC with 15% PP replacement
SCC20PP	SCC with 20% PP replacement
SCC25PP	SCC with 25% PP replacement
w/b	Water-binder ratio

Chapter 1

INTRODUCTION

1.1 Study Overview

Development of anti-cracking and anti-seepage structures has focused of research in recent years. In addition, it is important for constructions to be structurally safe and withstand fire conditions for a specific period of time to protect lives and properties (Han et al., 2005). In solving the problem of mass concrete structural cracks, several materials have been used in combination with the conventional concrete mixture to improve structural stability. Plastic wastes (PW) are among the commonly used aggregate materials for concrete production.

There are many kinds of PW, and recycling PW has not had significant growth globally. The daily use of plastic has increased enormously, resulting to high amount of PW in millions of tons, and PW is expected to reach 2.2 billion tons by 2025 (Han et al., 2005). Therefore, effective ways of utilizing PW must be explored to improve ways of PW recycling.

Polypropylene(PP), is a type of plastic classified as (artificial lightweight aggregate) that is explored as an effective material in mixture concrete, and it is a common PW. In most developing and underdeveloped countries, effective PW method is a pressing issue, and the constant demand for daily plastic usage grows exponentially with growing population, resulting to environmental pollution (Bhogayata et al., 2017). The constant demand for plastic shows that the concept of reuse and recycling plastic is needed to mitigate the environmental pollution associated to the environment.

The use of recycled plastic as an aggregate has gained recognition as a promising technology capable of contributing to resource efficiency in the construction industry. Using Polypropylene waste plastic in particular as a construction material has attractive qualities because of its composition, in addition to the environmental and financial benefits. More recently, using PP as an aggregate for mixture concrete is explored by researchers around the world (Kakooei et al., 2012; Mazaheripour et al., 2011). Polypropylene has some properties which will contribute greatly to structural stability.

Polypropylene have some crack resistance performance (He et al., 2011) that will contribute to improving structures. PP achieves great water proof through crack resistance. Therefore, infusing PP into concrete mixture can reduce early contraction deformation of concrete, hence improving impermeability of the concrete (Wong, 2004).

Light weight concrete was emerged as a promising modern technology with the rapid development of floating marine, high rise buildings and long span concrete structures. These are all credited to the excellent characteristics of lightweight concrete such as high specific strength, lower density, better thermal insulation and better energy absorption by replacing normal aggregate partially or totally with light weight aggregate such as PP (Xu et al., 2012).

1.2 Problem Statement

About 10% of the 1.3 billion tons of residential waste are generated from plastic waste, which is forecasted to increase to about 2.2 billion tones by 2025. This makes up a major part of land and water pollutant that affects the entire ecosystem. The construction industry also contributes to environmental problems from the use of cements, fine and coarse aggregate and other component of concrete mixture. The combination of environmental and financial problems of convention concrete provides a requirement for a more environmental friendly and less expensive concrete mixture. Therefore, the use of plastic waste such as PP as a component of concrete mixture is an attractive option. More importantly, structural cracks as a result of concrete mixture results to low quality structures, and project requiring high quality concrete needs concretes that are less likely to exhibit cracks. Therefore, exploring the effects of PP as a composite mixture concrete at different levels is important.

1.3 Study Objectives

It is imperative to find out ways of utilizing PP waste plastics as a replacement by the volume of natural coarse aggregate in Self-compacting concrete. The use of PP in mixture concrete will serve the environment and construction industries in many ways: reducing disposed PP materials that result to environmental pollution and reducing total construction cost. Studies have been made on using PP in mixture concrete, however, majority or the studies focus on using it as a fiber in the mixture concrete with the desire of improving certain characteristics of the concrete based on the positive characteristics of PP (Al-Tulaian et al., 2016; Kakooei et al., 2012; Yin et al., 2016).

In this study the main aim is to find out the changes on concrete fresh, mechanical, and physical properties, when shredded waste PP granules (PPWP) are added as a coarse aggregate partial replacement with different percentage, for water binder (w/b) of 0.45. The objectives to be investigated are:

1. Determining the influence of waste PP plastic aggregate on fresh concrete workability.
2. Studying the effect of PP plastic aggregate on concrete compressive strength (f_c), flexural strength (ff), splitting tensile strength (ft), and ultra sound pulse velocity.
3. Studying the effect of high temperature (100 and 200°C) on the physical and mechanical properties of self-compacting concrete.
4. Investigating the influence of PP plastic aggregate addition on flexural toughness.
5. Determining the optimum amount of coarse replacement by PP plastic aggregate.
6. Build conclusion and suggestions for future studies rely on the outcomes of the study

1.4 Outline of the Study

The study is organized in five chapters. Chapter 1 which is included introduction, Chapter 2 gives a literature review, showing the background of similar studies and their achievements. Chapter 3 (methodology) presents the experimental works in complete details, stating the steps and procedures according to standards. Chapter 4 shows the results and discussion of the experimental works, presenting details the findings. Chapter 5 concludes the thesis and summarizes the finding of the study.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

In today’s construction industry, there is a growing need for alternative techniques to improve the properties of concrete. An attractive option is the replacement of fine and coarse aggregate with other structural attractive materials. Given the environmental impact of plastic waste, globally, the management of plastic waste is seen as a serious environmental issue. The growing rate of urbanization and industrialization has increased the demand for concrete materials, and the construction aggregate has exceeded 10 billion tons per annum (Kumar et al., 2011), prompting growing research for the use of PP plastic waste as an aggregate in mixture concrete. The use of PP wastes presents an environmentally sustainable method of using PW. Literature on the use of PP in concrete is heavily concentrated on adding PP coarse in mixture concrete. However, a few numbers of studies have initiated using it as a fiber in mixture concrete.

(Ozbakkaloglu et al., 2017) performed an experimental study on the properties of concrete’s that were manufactured using recycled PP as a coarse aggregate. Using different contents of recycled PP aggregate, they produced eight batches of concrete. They studied the compressive behavior of concrete containing recycled PP when subjected to temperatures around the melting point of recycled polypropylene aggregate. The experiment also involves testing for compressive strength, flexural strength, elastic modulus, splitting tensile strength, fresh and hardened density and workability of the concretes. The result illustrated that the mechanical properties of concrete containing recycled PP are lower than concretes containing natural aggregates.

2.2 Ingredients of Concrete

Concrete is primarily made of (water, cement, fine and coarse aggregates and admixtures). A diagram showing the composition of concrete is shown in Figure 1. Concrete is made up of two main components: Aggregate and paste (Portland, 1916). The paste is made from the combination of cement and water, which is then used to bind sand and aggregate (fine and coarse). The paste is also composed of chemical mixture such as (water reducing mixtures and viscosity modifier) (Li et al., 2017). To improve the concrete performance and increasing some desired properties, fine and coarse aggregate are also replacing with other materials such as PP plastic waste.

2.2.1 Self-Compacting Concrete

In the early 1980’s, the problem of structural durability was of major interest in Japan (Okamura et al., 2003). To create durable concrete, this requires adequate compacting skills by workers. However, the decrease in the number of skilled workers in the construction industry in Japan led to the reduction of quality construction work in Japan. A solution for durable concrete structures independent of the construction workers quality is the use of self-compacting concrete SCC, capable of compacting into every corner of the framework using its own weight and without the need of vibrating component (Okamura & Ouchi, 2003). Okamura in 1986 proposed the necessity for this type of concrete.

The first prototype of self-compacting concrete was developed in 1988 by professor Okamura at the University of Tokyo using already available materials in the market (Okamura, 1997; Okamura & Ouchi, 2003). Figure 3 shows the steps for achieving the self-compatibility by using the following method (Okamura and Ozawa,2003):

1. Limited content of aggregate
2. Minimal water-powder ratio
3. Use of superplasticizer

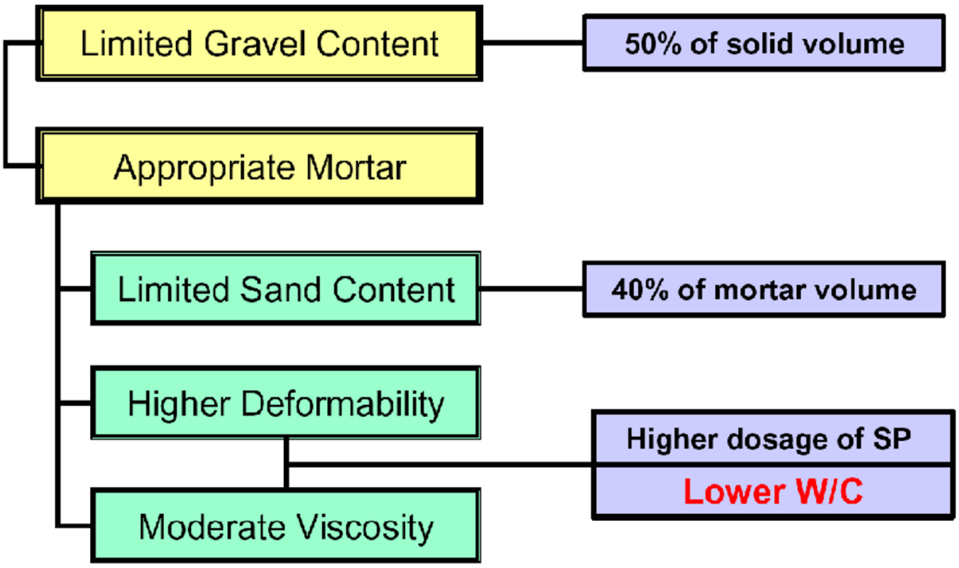

Figure 2.1: Method of Achieving Self-compactablity
Source: (Okamura & Ouchi, 2003)

The following 3 stages define SCC (Okamura & Ouchi, 2003)

- Fresh: self-compactability
- Early aging: avoiding initial defects
- After hardening: protection against external, factors

The Japanese Ready-Mixed Concrete Association (JRMCA) introduced the ‘‘Standardized mix design method of SCC’’, a simpler version of Okamura’s method for producing SCC (Association, 1998). The method employed uses a large amount of powder material, and a water/binder ratio of <0.30.

The Laboratory Central Des Ponts et Chausses (LCPC), for the Swedish Cement and Concrete Research Institute (CBI) developed the BTRHEOM rheometer and RENE LCPC software. This method is difficult to implement without purchasing the software (De Larrard, 1999)

Some research groups in both mainland China and Taiwan proposed a different mix design for HPC. Hon’s group of mainland China did not make their mix design procedure public, however, they offered useful insight. They concluded that a low past volume reduces compressive strength if vibration is not employed in the mixing process, and it also impairs the passing ability of concrete (Chai, 1998). The general advantages of SCC’s are (Clans et al., 2008):

- Flow properties: making it easy to cast complex reinforcement and around closed spaces
- Reducing casting error such as honey combs
- Provide high surface quality
- Easy pumping into inaccessible framework with top side shuttering

The SCC is in limited use in construction despite its advantages, this is mostly as a result of its advantages (Lotfy et al., 2014). Therefore it is easy to conclude that using light weight aggregate instead of the normal weight aggregate in SCC will produce a new HPC (Li et al., 2017). The assumption here is that, the light weight replacement in SCC will produce a type of HPC known as lightweight aggregates self-consolidating concrete (LWASCC). Consequently combining the advantages of light weight aggregate and SCC (Lotfy et al., 2015).

Light weight aggregates that could be used in place of the normal aggregate is PW such as polypropylene PW. The use of such PW as an aggregate in concrete or SCC will combine advantages of LWAC and SCC. This may present some attractive qualities such as reduced load beads, thermal insulation, proved fire resistance, filling and passing ability (Wu et al., 2009).

To improve the performance of concrete in construction, the physical, chemical and mechanical properties must be examined. The following factors that are observed are as follows: workability of the concrete, compressive strength of the concrete, tensile strength of the concrete, stress-strain reduction of the concrete and water absorption capacity of the concrete.

2.3 Concrete Workability

Cement paste is made from a mixture of cement, water and cementitious materials, all of which take an active part to bind the concrete component together. Among the cement paste materials, water is known to be the most important component.

Hydration refers to the hardening of concrete through water. Cementitious hydration is produced by the chemical reaction between water and cement (Kosmatka et al., 2011). (Gambhir, 1995, 2013) describes water as a lubricant that exists in concrete between fine and coarse aggregate. The lubrication between fine and coarse aggregate makes the concrete workable.

A physical characteristic of concrete is its workability. Workability covers multiple properties of concrete which includes, mobility, finish-ability and compatibility of fresh concrete (Anderson et al., 2003). The primary components of concrete (water, cement, fine and coarse aggregates and admixtures) are important in improving the workability of concrete. The aggregate content of the concrete and the lubrication of water is important for the concrete workability. Therefore, replacing the fine and coarse aggregate with polypropylene PW affects the workability of the concrete.

2.3.1 Effects of Polypropylene on Concrete Workability

(Ozbakkaloglu et al., 2017) studied the workability of concrete containing PP as a coarse aggregate. Their experiment shows a significant reduction in the concrete's workability due to the non-uniform and angular shape of the coarse PP aggregate, which also negatively affects the flow and compaction of the concrete. They used a relatively high w/c ratio in the mixes to achieve a workable mix without adding superplasticizer.

A study by (Xu et al., 2012) on the mechanical observed when expanded PP lightweight aggregate is used in concrete shows low degree of compaction in the specimen when there is high amount of polypropylene aggregate. It was observed that the workability of the concrete decrease with increase in expanded polypropylene ratio. This is attributed to the hydrophobic ratio and increase in surface area of the polypropylene beads.

2.4 Compressive Strength

Compressive strength is the most significant mechanical property of concrete. It shows the maximum resistance of a concrete to axial loading when it is horizontally applied with a special machine. The unit f compressive strength is Kilo-newton per millimeter square (MPa) or pound per inch square (psi).

Compressive strength defines the maximum load (stress) that an area of concrete can withstand. The test is conditioned to be made at age 28-days of the concrete (Kosmatka et al., 2002). Researchers identify compressive strength to be the most critical mechanical property of concrete. It is used as a quality control and specification indicator in the construction industry (Gambhir, 1995; Neville et al., 1987).

The compressive strength of the resulting specimen is the most important mechanical property investigated when new materials such as silica fume, glass powder, fly ash, ground granulated blast-furnace slag etc are added to a concrete (Vijayakumar et al., 2013). Therefore, when polypropylene is used as an aggregate in mixture concrete, the compressive strength of the resulting specimen is thoroughly tested. It is used to estimate the other mechanical properties of concrete (Ozbakkaloglu et al., 2017)

2.4.1 Effects of Polypropylene on Concrete Compressive Strength

The experiment of Ozbakkaloglu (Ozbakkaloglu et al., 2017) shows a decrease in compressive strength as the percentage of recycled polypropylene aggregate increases. This can be attributed to the lower strength between the coarse recycled polypropylene aggregate and the cement paste. In addition to the hydrophobic nature of recycled polypropylene which helps restrain cement hydration reaction close to the surface of the recycled polypropylene aggregate

One researcher (Xu et al., 2012) stated that increasing the volume of expanded polypropylene aggregate and W/C, decreases the compressive strength. Their study also states that the volume of expanded polypropylene has significant effect on the compressive strength in 7 days than 28 days. It also shows that when cement content is increased in the mixture concrete, compressive strength first falls and rises.

2.5 Modulus of Elasticity

Modulus of elasticity of concrete shows the concrete's ability to deform elastically. It is considered as an important mechanical property of concrete. Mathematically, it is defined as the slope of the stress-strain relation curve at 40% ultimate compressive strength. If a concrete exhibits high modulus of elasticity, it shows the concrete's resistance to deformity (Tia et al., 2005).

The component of mixture concrete affects the modulus of elasticity. It is therefore imperative the materials used to replace fine and coarse aggregate in the mixture concrete maintains certain characteristics. In addition, the strong relationship that exists between modulus of elasticity and strength shows that the factors that affects concrete may affect the modulus of elasticity (Neville & Brooks, 1987).

2.5.1 Effects of Polypropylene on Modulus of Elasticity of Concrete

The study of (Ozbakkaloglu et al., 2017) show that using high percentage of recycled polypropylene aggregate in the mixture resulted to a low elastic modulus compared to the concrete with natural coarse aggregate. This results to elastic incompatibility and stress concentration which causes weakness at the ITZ between the recycled polypropylene aggregate and cement mixture. Their result is consistent with that of Saikia (Saikia et al., 2014).

The study of (Xu et al., 2012) using expanded polypropylene beads as concrete aggregate considered elasticity modulus at 40% of the ultimate stress. The result shows their three-series test shows elasticity modulus to be similar to that of normal brick masonry.

2.6 Splitting Tensile Strength of Concrete

Tensile strength is a basic mechanical property of concrete. It shows the maximum tensile stress (load) tolerated by a concrete before failure. Concrete is weak under tension than compression due to its brittle nature. When tensile forces are exerted in a concrete, cracks are developed. Therefore, for safety and structural stability, it is important to identify the load under which the cracks are initiated.

Split tensile strength is a common method for identifying the strength of a concrete. It is also known as indirect tensile strength test. The results are mostly more than the direct tensile strength test.

In applying the ASTM standard C496/C496M – 11 split tensile strength test, “a diametric compressive force along the length of a cylindrical concrete specimen at a rate that is within a prescribed range until failure occurs” (p.1). Tensile stresses is applied on the plain that contains the load through the loading process, and compressive stresses is applied immediately in the region around the applied load.

Tensile strength of a concrete is known to be the determined by the splitting tensile strength, therefore, factors affecting the strength of a concrete would also influence the tensile strength of the concrete. A study by Ozbakkaloglu (Ozbakkaloglu et al., 2017) on short term mechanical properties of concrete containing recycled polypropylene coarse aggregate conducted the splitting tensile strength at age 28 days of their specimen. The results show that with an increase in percentage of recycled polypropylene aggregate, the splitting tensile strength of the concrete decreases. The result can be explained by evidence of weak bond between the recycled polypropylene aggregate and cement paste as a result of the hydrophobic and smooth surface of recycled polypropylene. Thus, restraining the cement hydration close to the surface of recycled polypropylene aggregate. Since there is strong relationship between compressive strength and other mechanical properties of concrete (Ozbakkaloglu et al., 2017). Figure 5 shows the relation between compressive strength and splitting tensile strength.

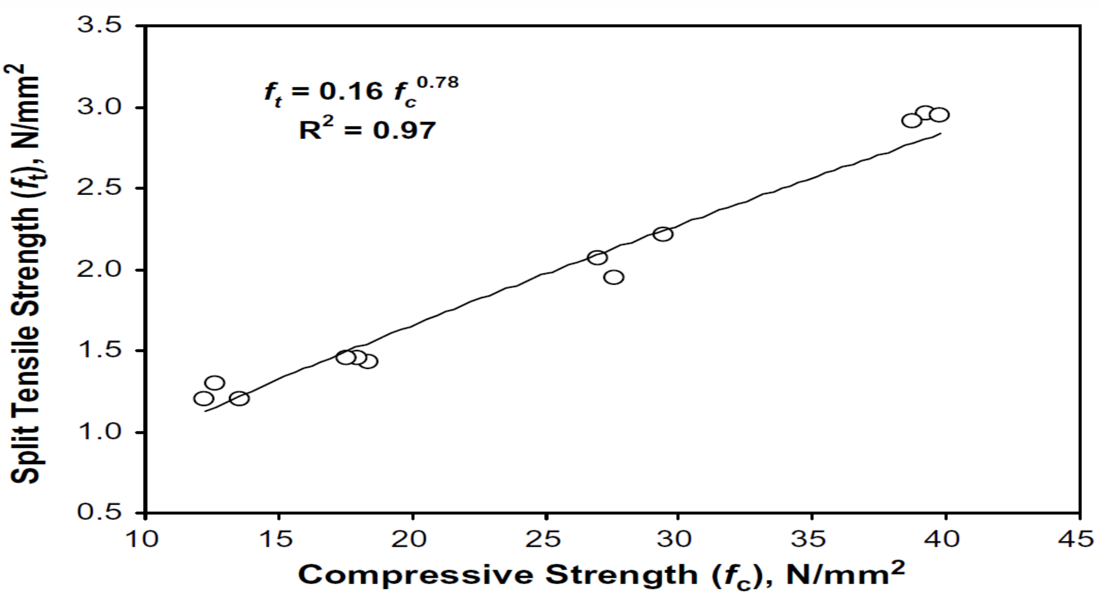

Figure 2.2: Relationship between Compressive Strength and Splitting Tensile Strength
Source: (Tang et al., 2008)

Factors affecting tensile strength test of a concrete includes the following:

- Component material: The materials used in mixture concrete influence the strength of the concrete. It also contributes to the quality of the concrete.
- Loading rate: The loading must be don rapidly to achieve a high splitting tensile strength result (Shu Zhang et al., 2016)
- Dimension (Diameter and length) of specimen: The cylindrical length of the specimen mainly reduces the variability of a long test specimen but does not

necessarily affects the test result. However, the diameter affects the splitting tensile strength results (Lamond et al., 2006).

- Bearing strips: To distribute the applying load and conform the concrete sample, the ASTM C496/C496M – 11 standards recommend two bearing strip of 3.0 mm and thick plywood of 25 mm (Lamond & Pielert, 2006)

2.6.1 Effects of Polypropylene on Splitting Tensile Strength

There is a decrease in splitting tensile strength as the percentage of recycled polypropylene increases as observed by (Ozbakkaloglu et al., 2017). This is as a result of the weak bond between the recycled polypropylene aggregate and the cement due to the smooth surface and hydrophobic nature of polypropylene aggregate. This restricts the cement hydration near the surface of the polypropylene aggregate.

2.7 Stress-strain Relation of Concrete

The relationship between stress and strain of a concrete in the presence of continuous loading is represented by the stress strain curve under the control of stress or strain. The stress-strain relations are important input parameters to predict the performance of reinforced concrete members including their shear and flexural behavior. The localization of failure identifies the significant factors in the stress-strain curve (Komlos, 1969).

Many studies have concluded that properties of interfacial transition zone (ITZ) are accountable for the properties that concrete exhibits (such as the concrete's failure behavior) when it is subjected to uniaxial loading (Xiao et al., 2013).

The factors affecting stress-strain relations include:

- Aggregate to cement ratio

- Water to cement ratio
- Aggregate grading
- Curing condition
- Loading rate
- Specimen length

The shape of a uniaxial stress-strain diagram is influenced by the following conditions:

1. The age of the specimen and curing condition
2. The characteristics of the concrete

   Aggregate content

   Cement content

   Water cement ratio

   Concrete unit weight
3. The conditions of testing

   Strain rate

   Sample shape and size

   The type of loading (cycling, preloading, etc)

   Stiffness of the testing machine

(Xiao et al., 2013) concludes that, in concrete that contains recycled aggregate materials, the mechanical properties between ITZs and mortar matrices is significantly influenced by the overall relationship between stress-strain.

(Xu et al., 2012) observed the stress-strain behavior of nine specimen under compression. Their experiment was on expanded polypropylene beads as concrete aggregate. They observed that the diagram is similar to that of normal weight concrete, with an increase in compression strength, the elastic portion of the stress-strain curve increases and the slope increases.

2.8 Water Absorption Capacity

The importance of testing the water absorption capacity is to test the durability of concrete for corrosion in reinforcement, sulfate attack, alkali-aggregate expansion, chloride ingress and freeze-thaw damage (Parrott, 1992).

(ASTM C642 − 13) states that water absorption is the percentage increase in weight of over dry concrete sample after immersing it in water for some period. It is used to identify high quality concrete. Important mechanical properties of concrete such as permeability, compressive strength and resistance to sulfate attack durability can be predicted from the water absorption capacity (SP Zhang et al., 2014).

The following factors are capable of affecting the water absorption capacity of concrete (Castro et al., 2011)

- Environmental climate conditions,
- Primary concrete components: Water, Cement, Fine and coarse aggregates, Admixtures,
- Mixture Proportion
- Volume of aggregate,
- Water cement ratio
- Relative humidity

2.8.1 Effects of Polypropylene on Water Absorption Capacity

Literature also shows some studies aim at improving the properties of self-compacting concrete by fine and coarse aggregate with light weight aggregate to produce the Self-

Compacting Concrete (LWSCC). Few studies have experimented on using polypropylene in conjunction with self-compacting concrete.

The use of recycled waste plastic (polyethylene) as a fine aggregate in place of sand in the manufacturing of self-compacting mortar was examined by (Safi et al., 2013). They substituted the sand with the plastic waste at different percentages (0%, 10%, 20%, 30% and 50%) by the weight of sand. At age of 28 days the observed that mortars with 50% shows a better result in terms of density than other proportions, and they have acceptable mechanical properties of lightweight materials. A microscopic study shows that the interfacial zone (plastic-binder) exhibit adhesion between the cement paste and plastic.

(Mazaheripour et al., 2011) used polypropylene fibers on SCC and produced the LWSCC. They modified and improved the LWSCC developed by Nan-su (Nan-su et al 2003). They studied the performance of the specimen at the fresh conditions and the mechanical properties were examined at age 28 days. At 75% lightened SCC, the fresh properties were immensely affected. In general, the use of polypropylene fibers in LWSCC reduced the rate of slump flow over super plasticizer (SP). The polypropylene fibers did not affect the compression strength and elastic modulus of SCC, but the tensile strength increased by 14.4% when the fibers are at their maximum.

Chapter 3

RESEARCH METHODOLOGY

3.1 Introduction

The foremost purpose of this experimental study is to investigate the use of 5, 10, 15, 20, 25 and 30% of polypropylene waste plastic, as a replacement by the volume of natural coarse aggregate in self-compacting concrete mixtures with 0.45 w/b ratios. With the intent to acquire SCC, silica fume was added at 10% and Glenium at 1.75% of the weight of the cement. The main goal was to obtain SCC thrush the addition of the aforementioned percentages of polypropylene waste plastic (PPWP) in our mixtures and also to measure the effects of that replacement on the physical, mechanical and thermal properties of SCC concrete after 28 days. To this end, the following experiments were performed:

- Workability tests: Slump flow test, L-box test, V-funnel test.
- Degradation tests against heat at 100°C and 200°C.
- Weight of specimens before and after heating test.
- Ultrasonic pulse velocity before and after heating test.
- Compressive strength (f_c) test before and after heating test
- Split tensile strength (f_t) test before and after heating test.
- Flexural strength (f_f) and toughness tests before and after heating.
- Measuring the width of cracks before and after heating test.

This chapter covers the description of the materials used in the above-listed experiments, explains the ASTM codes and other requirements utilized during experimentation, the techniques of the equipment's used, and test techniques.

3.2 Materials Used

The materials which have been used in the experimentations of this study is described in the following sections:

3.2.1 Cement

Portland composite cement EN 197-1 - CEM II / B-M (S-L) 32.5 R was used in our experiments. It has a modest strength expansion and very favorable processing properties. The chemical and physical properties of the cement are shown in Table 3.1 below:

Table 3.1: Chemical and Physical Analysis of Cement

CEM II/B-M 32,5)

Chemical Properties	Results	Standards
Insoluble Residue (%)	0.10	EN 196-2
Loss on ignition (%)	10.88	
SO_3 (%)	2.24	
SiO_2 (%)	18.72	
CaO (%)	60.44	
Free CaO (%)	1.00	
MgO (%)	2.00	
Al_2O_3 (%)	4.04	
Fe_2O_3 (%)	2.56	
Cl (%)	0.00	EN 196-21
Physical and mechanical Properties	**Results**	**Standard**

Specific Gravity (g/cm^3)		3.00	EN 196-6
Fineness (cm^2/g)		4.007	
90 µm Sieve Residue (%)		0.26	
45 µm Sieve Residue (%)		5.24	
Initial Setting Time (minutes)		18.5	
f_c (MPa)	2 days	15.78	EN 196-1
	7 days	29.86	
	28 days	41.33	

3.2.2 Mixing Water

Clean tap water, which is free from acids, alkalis, oils and organic materials, was used for all concrete mixtures and the curing system.

3.2.3 Fine and Coarse Aggregates

Crushed fine aggregate, having maximum size of 5 mm in diameter referred as a sand were used in this study. To find out gradation based totally on ASTM general, C136M-14 sieve analysis was performed and managed using C33/C33M-16 as shown in Figure 3.1.

On the other hand, to be able to evaluate the particle size distribution of 10 mm in maximum size coarse aggregates, sieve analyses based on the standard ASTM C136M-14 has been performed and controlled by means of ASTM C33M-16 as shown in Figure 3.2.

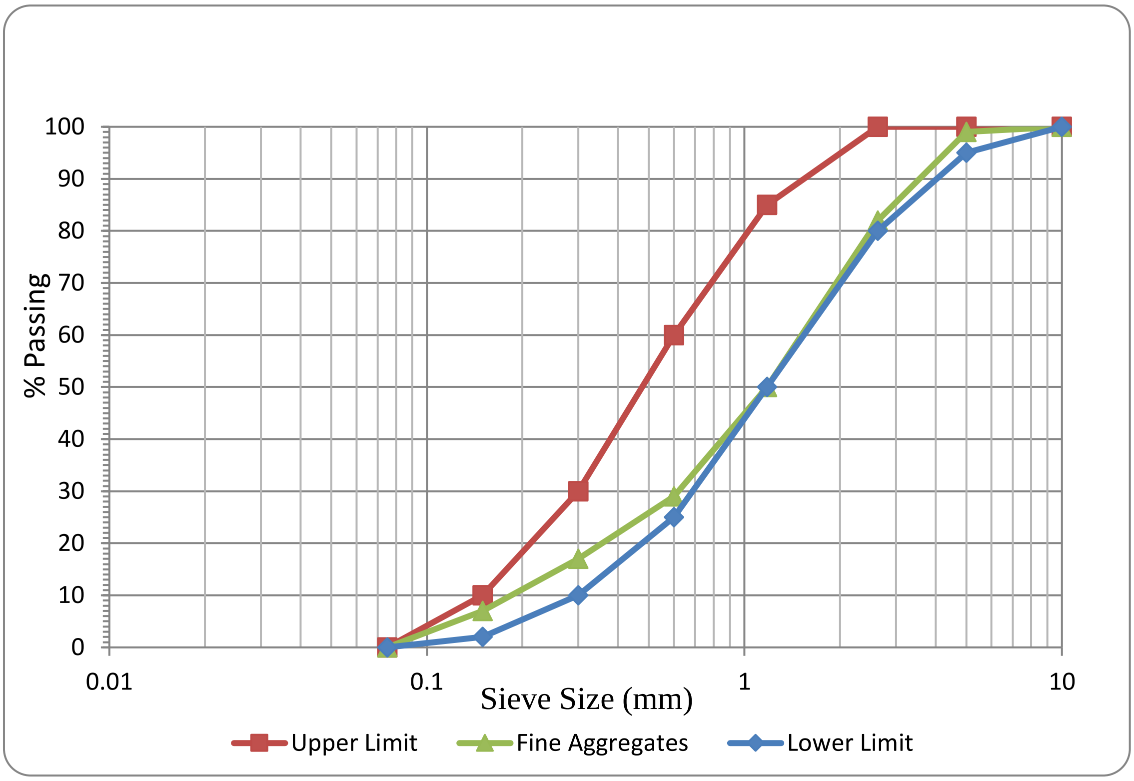

Figure 3.1: Sieve Analysis of Crushed Fine Aggregate.

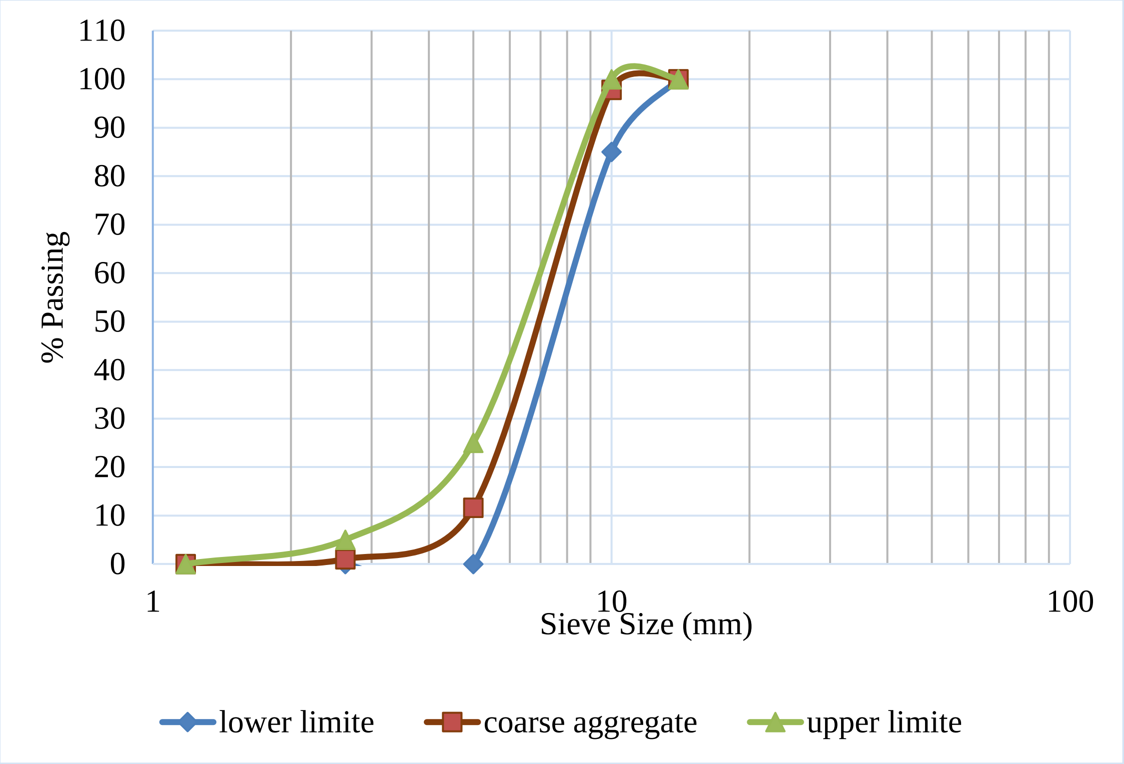

Figure 3.2: Coarse Aggregate Sieve Analysis, D_{max} = 10 mm

Additionally, the water absorption and specific gravity of fine and coarse aggregates are shown in Table 3.2. The dust content in fine and coarse aggregates was 16.5 % and 4.2 % respectively (ASTM C 117, 2004).

Table 3.2: Water Absorption and Specific Gravity of Fine and Coarse Aggregates (SSD)

Type of Aggregate	Bulk specific gravity		Water absorption (% of dry mass)	Apparent specific gravity
	DRY	SSD		
Fine aggregate	2.51	2.57	1.12	2.67
Coarse Aggregate	2.42	2.45	1.64	2.51

3.2.4 Silica Fume

The silica fume utilized in these tests is a byproduct of producing silicon metallic alloys. Due to its chemical and physical properties, concrete containing silica fume tends to be excessively strong and durable. Silica fume was added at 10 % of the weight of the cement. Table 3.3 below illustrates the chemical and physical properties of the silica fume used in all samples.

Table 3.3: Chemical and Physical Characteristics of Silica Fume

Property	Amount
SiO_2 content	82.20 %
Al_2O_3 content	0.50 %
Fe_2O_3 content	0.42 %
CaO content	1.55 %
MgO content	0.00 %
SO_3 content	3.03 %

Loss of ignition	5.66 %
Fineness as surface area	29000 (m^2/kg)
Specific gravity	2.2

3.2.5 Polypropylene

Polypropylene (PP), also referred to as polypropene, is a thermoplastic polymer utilized for a number of purposes. It can be produced in a number of different structures, thus allowing it to be used in various settings, including packaging and labeling, textiles, plastic components and reusable boxes of numerous sorts, laboratory devices, automobile components, and scientific devices. A white-colored material, PP is mechanically rugged and is resistant to a number of bases, acids, and chemical solvents. PP is the second most-widely produced artificial plastic in the world, after polyethylene.

The density of PP used was between 0.895 and 0.92 g/cm³, with a melting point between 130 and 171°C. The PPWP chemically represented as $(C_3H_6)_n$ was used in our mixtures and is shown in Figure 3.3 below.

Figure 3.3: Crushed Polypropylene Waste Plastics

3.2.6 Superplasticizer

Master Glenium 27 is a high-range water-reducing admixture, primarily based on modified polycarboxylic ether polymers. It was used as a superplasticizer in all mixtures at two different percentages: 1.75% and 3% of the weight of the cement.

3.3 Mix Design

Mix design can be characterized as the manner in which all the appropriate ingredients of concrete are chosen and deciding their relative quantities. The goal is the production of concrete with a certain base quality and strength that is as durable as economic as possible. The mix designs are contained in Table 3.4.

Table 3.4: Quantities and proportions of mixing materials for seven different mixes

Type of concrete	Cement (kg/m3)	PP (kg/m3)	Water (kg/m3)	FA (kg/m3)		CA (kg/m3)	SF (10 %) (kg/m3)	SP (kg/m3)	w/b (kg/m3)
				(3 mm)	(5 mm)	(10 mm)			
SCC0PP	400.00	0.00	198.00	457.5	457.5	812.00	40.00	7.70	0.45
SCC5PP	400.00	13.43	198.00	475.5	475.5	773.20	40.00	7.70	0.45
SCC10PP	400.00	26.86	198.00	475.5	475.5	734.40	40.00	7.70	0.45
SCC15PP	400.00	40.29	198.00	475.5	475.5	695.63	40.00	7.70	0.45
SCC20PP	400.00	53.72	198.00	475.5	475.5	656.83	40.00	7.70	0.45
SCC25PP	400.00	67.15	198.00	475.5	475.5	618.04	40.00	13.20	0.45
SCC30PP	400.00	80.58	198.00	475.5	475.5	579.20	40.00	13.20	0.45

FA: fine aggregate; CA: coarse aggregate; SF: silica fume; SP: super-plasticizer; W/b: water to binder ratio.

3.4 Experimental Program

To be able to test the impact of replacing coarse aggregate with PP waste plastics, seven different percentages (0, 5, 10, 15, 20, 25 and 30 %) of PP were substituted to coarse aggregates respectively. Accordingly, seven different types of mix designs were prepared for the essential tests. The method of the experiments was an evaluation of every proportion of natural coarse aggregate replacement with PP as compared with the control mix where 0 % normal coarse aggregate had been replaced with PP.

3.4.1 Concrete Mixing Procedure

All concrete mixtures had been combined with a 0.05 m³ potential mixer. The dry materials had been introduced to the mixer in line with the following order: half of the coarse aggregates combined with PP, half of the fine aggregates combined with cement and silica fume; then the other halves of the coarse and fine aggregates. They were blended for about 60 seconds, after which water (or blended water and superplasticizer) was added, and they were subsequently mixed for an additional 150 seconds.

3.4.2 Fresh Concrete Tests, Workability

In order to determine the effects of seven different percentages of PP (0, 5, 10, 15, 20, 25, and 30) % as a coarse aggregate replacement material on the workability of self-compacting (SSC) with 0.45 w/b ratios, the slump flow, L-box and V funnel tests were applied.

3.4.2.1 Slump Flow Test

The basic equipment used for this test is the same as for the conventional Slump test (Figure 3.4). The test method differs from the conventional one in the way that the concrete pattern is positioned into the mold and it has no reinforcement rod. Here, the diameter of the spread of the pattern is measured, as well as the horizontal distance, in contrast to the vertical slump measured in the conventional test. The recommended limit for the slump flow test for SCC is between 650-800 mm.

Figure 3.4: slump flow test

3.4.2.2 L Box Test on Self Compacting Concrete

This test assesses the flow of the concrete in an L box. The apparatus used for the test is shown below in Figure 3.5. About 0.014 m^3 of concrete was used to perform the test. The samples were poured into the vertical section of the apparatus and left to stand for 1 minute. Afterwards, the sliding gate was opened and the concrete was allowed to flow into the horizontal section. When the concrete stopped flowing, the distances ‘H1’ and ‘H2’ were measured, and lastly, the value for H2/H1 was calculated (see Table 6). The recommended range for the resulting value of H2/H1 for SCC is between 0.8 and 1.

Figure 3.5: L-Box test

3.4.2.3 V-funnel Test:

The V-funnel test was developed in Japan and was utilized by Ozawa et al. The system consists of a V-fashioned funnel (shown in Figure 3.6). The funnel is filled with concrete and the time taken for it to flow through the apparatus is measured. This test gives account of filling capability (flowability). The inverted cone form suggests that any possibility of the concrete to dam is mitigated in the results.

The recommended limits for the V-funnel values of fresh SCC is between 6 – 12 seconds.

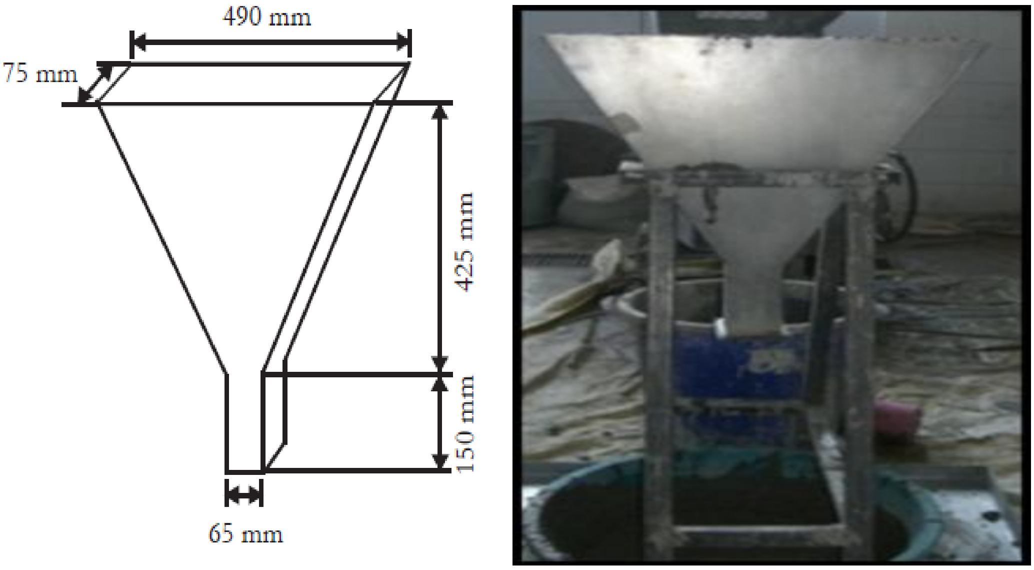

Figure 3.6: V-funnel Test

3.4.3 Specimen Preparation and Curing Process

In this experimental study, four specific sizes and styles of specimens were produced so as to study the behaviors and properties of hardened concrete. These are: three big cubes (150mm), three small cubes (100 mm), three cylinders (100 mm × 200 mm) and three beams (500 mm × 100 mm × 100 mm). Firstly, the molds were wiped clean and oiled with a thin layer of oil in order to avoid a chemical reaction between the concrete and the metallic molds, and to ensure a smooth demolding of the specimens. Secondly, after completing the fresh concrete tests and due to generation of self-compacting concrete, there was no need to put the specimens in the vibration machine. Consequently, the molds were then immediately filled with concrete and placed in the curing room at a relative humidity of 99 % with a temperature of 20 ºC. The specimens were subsequently demolded after twenty-four hours.

Figure 3.7: Picture of Produced Specimens – Cubes, Cylinders and Beams

The samples were remolded after one day and placed in a water tank at a temperature of 20ºC for 28 days. After 28 days of curing, the specimens were ready for further tests.

Figure 3.8: Water Tank for Curing

3.4.4 Degradation tests against heat at 100˚C and 200˚C

In order to measure the effects of heating at 100˚C and 200˚C; on the ultrasound readings, weight, f_c, and f_t of specimens containing seven different percentages (0, 5, 10, 15, 20, 25 and 30 %) of PP replacements, 90 small cubes (100 mm) were used (see Figure 3.9).

According to ASTM D2115 code, the cubes were placed separately in the oven at 100˚C and 200˚C for 4 hours each. For each temperature, the specimens were placed in the oven at 0˚C with a 10˚C increase in temperature per minute until the temperature was at either 100˚C or 200˚C, respectively. Afterwards, the oven was turned off for 15 hours to allow it cool down, after which the specimens were removed from the oven for two hours to measure their ultrasound, weight, f_c and f_t.

Figure 3.9: Oven Used for Heat Treatment with 200˚C Capacity

3.4.5 Surface Crack Detection of Specimens before and after Heating Test

The stereo microscope, shown in Figure 3.10 below was used to observe and measure the differences in the width of cracks on the surfaces of 100 mm small cubes incorporated with seven different proportions of PP waste plastic aggregate in seven different proportions (0, 5, 10, 15, 20, 25, and 30) % and subjected to heating at two different temperatures as 100˚C and 200˚C.


Figure 3.10: Stereo Microscope Setup

3.4.6 Weight Change Measurement of Specimens before and after Heating test

To measure the effect of heating on weight change (loss) of specimens at two different temperatures as100˚C and 200˚C, 90 small cubes (100mm) including seven different percentages (0, 5, 10, 15, 20, 25, and 30) % of PP were weighed before and after the heating test.

3.5 Testing for Hardened Concrete

In total, four tests were performed on the samples in their hardened state:

Compressive Strength (f_c) Splitting Tensile Strength (f_t), Flexural Strength (f_f), and Crack Detection.

3.5.1 Compressive Strength Test

Eighteen cubes (150 mm) were used to test the changes in f_c between the control specimen with 0 % replacement PP and the other specimens including six different percentages (5, 10, 15, 20, 25, and 30) % of PP replacement to natural coarse aggregates in the mixtures after curing for 28 days.

Figure 3.11: Crushed Sample Contained 25% of PP Under Compression Load.

3.5.2 Splitting Tensile Strength

To determine the effects of using seven different percentages of PP (0, 5, 10, 15 ,20 and 25, 30 %) as a replacement for natural coarse aggregate on f_t after curing for 28 days, eighteen cylinders (with L = 200 mm and D = 100 mm) were used. For this test, the cylinders were placed on the testing machine with the axially applied load, as is shown in Figure 3.12.

Figure 3.12: Splitting Tensile Test Arrangement and Crushed Specimen.

3.5.3 Flexural Strength and Toughness Test

Eighteen beams (500 mm × 100 mm × 100 mm) containing seven different percentages (0, 5, 10, 15, 20, 25 and 30) % of PP replacement were used to calculate the variation in flexural toughness (ductility) between the control (0 % PP) and the others.

This test technique evaluates the flexural performance of toughness parameters in terms of areas under the load-deflection curve obtained by testing a simply supported beam under third-point loading. The beams were placed on the f_f machine, which progressively applied load on the beams until they were crushed. LVDT s were used to draw the Load-deformation diagrams (see Figure 3.13).

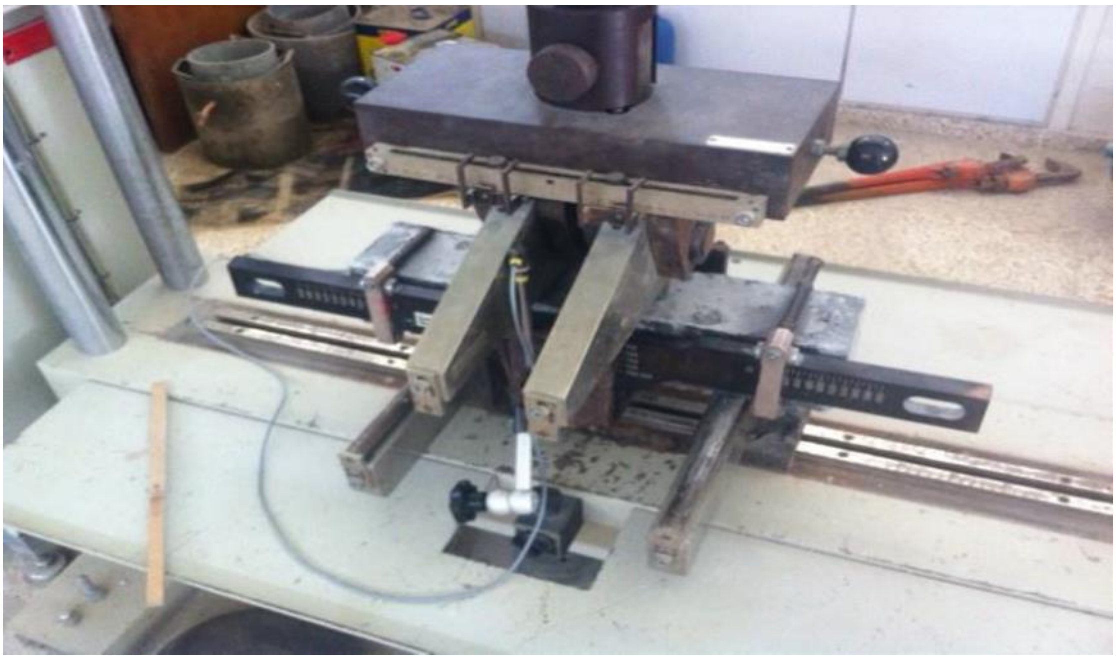

Figure 3.13: Measurement of Vertical Displacements under Three Point Loading Test

3.5.4 Detection of Deteriorations by Means of Ultrasonic Pulse Velocity Method before and after Heating Test

An ultrasonic pulse speed check is an in-situ, nondestructive test to check the quality of concrete and natural rocks according to the ASTM C597 code. In this test, the strength and quality (deteriorations) of the concrete or rock are found by measuring the speed of an ultrasonic pulse passing through a concrete structure or natural rock formation. This test is conducted through the passing of an ultrasonic wave pulse through the concrete to be tested and measuring the time taken by pulse to completely pass through the specimen. Higher velocities suggest a better quality and continuity of the material, while low velocities may additionally indicate concrete with many cracks or voids.

In this experiment, the ultrasound was measured before and after putting the small cubes (100 mm) in the oven at two different temperatures (100ºC and 200ºC) for 4 hours with a 15 hour cooling period.

Figure 3.14: Ultrasound Pulse Velocity Measurement

Chapter 4

EXPERIMENTAL RESULTS AND DISCUSSIONS

4.1 Introduction

In this chapter, the experimental results for SCC specimens incorporated with PP waste plastics are tabulated in tables or drawn in graphs and discussed. The effects of PP waste plastics being used to replace coarse aggregate in seven different percentages (0, 5, 10, 15, 20, 25 and 30%) were analyzed for 0.45 w/b SCC mixes. In all mixes, more than 1.75 % of super plasticizer was used in order to achieve SCC requirements.

4.2 Effects of PP Waste Plastics on Workability of SCC Mixes

Fresh concrete test results for the slump flow, V-funnel and L-box tests are given in Figure 4.1, Figure 4.2 and Figure 4.3, respectively. Table 4.1 includes all the data used in the three figures.

As can be seen in Figure 4.1 and Figure 4.2, when the proportion of PP replacement increases from 0 % up to 25 %, slump flow decreases from 650 mm to 500 mm. The value of H_1/H_2, which is related to the L-box test, also decreased from 0.9 sec to 0.73 sec. On the other hand, Figure 4.3 shows that the V-funnel value increased from 7 sec to 12 sec when the proportion of PP replacement increases to 25 %. This means that the workability of self-compacting concrete reduces when the proportion of PP replacement increases. Because, when PP waste plastics are added to the SCC concrete mix, they increase the viscosity and because they are evenly distributed throughout the mix, the overall workability of the concrete decreases. Here, it is important to explain that, SCC was not satisfied for 30 % PP replacement because the values of the slump flow test (300 mm), L-Box test (0.314) and V-funnel test (17sec) were outside of the recommended range for each.

Table 4.1: Effect of Substituted PP Waste Plastics on Fresh SCC Properties

Mixtures	Results of fresh concrete test for SCC			Self-compacting concrete
	Slump flow test (mm)	L-Box test (H1/H2)	V-Funnel test (sec)	
SCC0PP	650	0.90	7.00	Satisfied
SCC5PP	630	0.87	8.50	Satisfied
SCC10PP	600	0.85	10.00	Satisfied
SCC15PP	580	0.84	11.00	Satisfied
SCC20PP	550	0.82	11.50	Satisfied
SCC25PP	500	0.81	12.00	Satisfied
SCC30PP	430	0.73	17.00	Not Satisfied

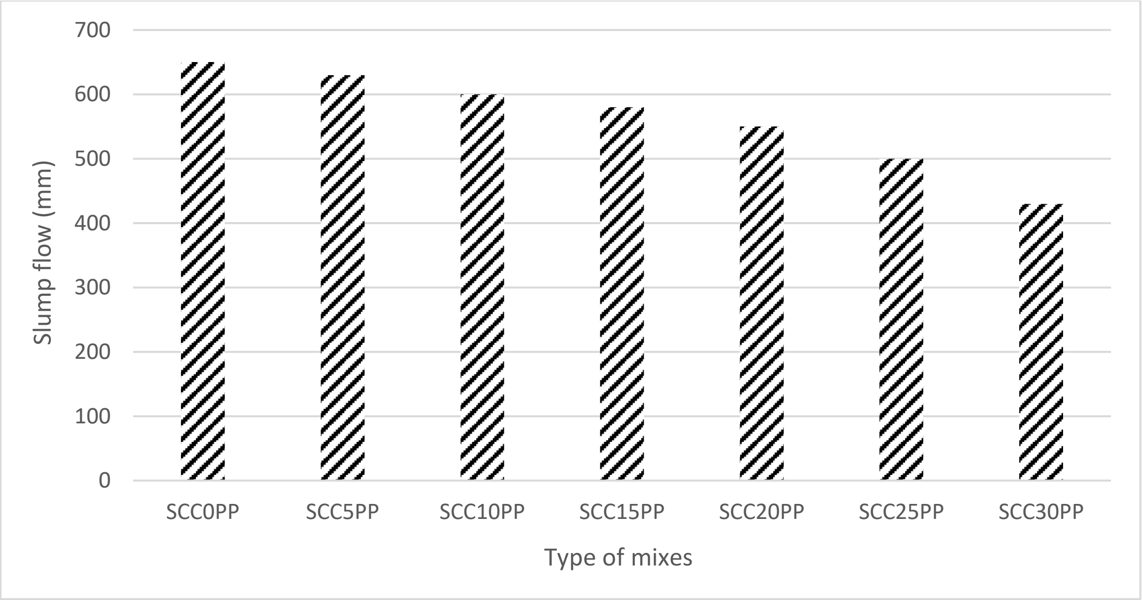

Figure 4.1: Effect of Substituted PP Waste Plastics to Coarse Aggregate on Slump Flow of SCC Mixes.

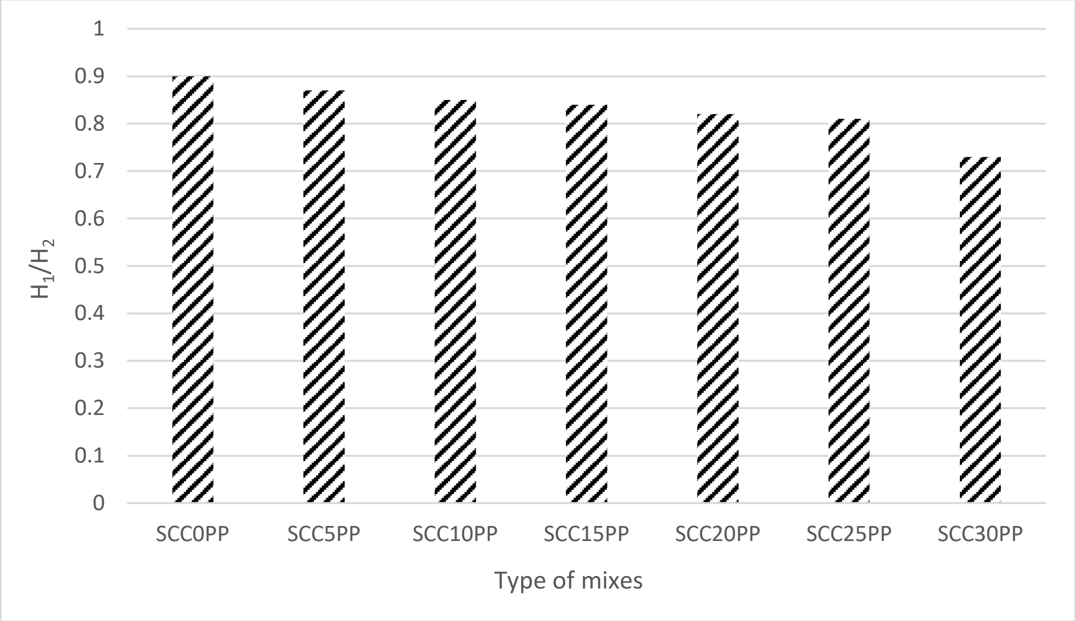

Figure 4.2: Effect of Substituted PP Waste Plastics to Coarse Aggregate on Fluidity of SCC Mixes.

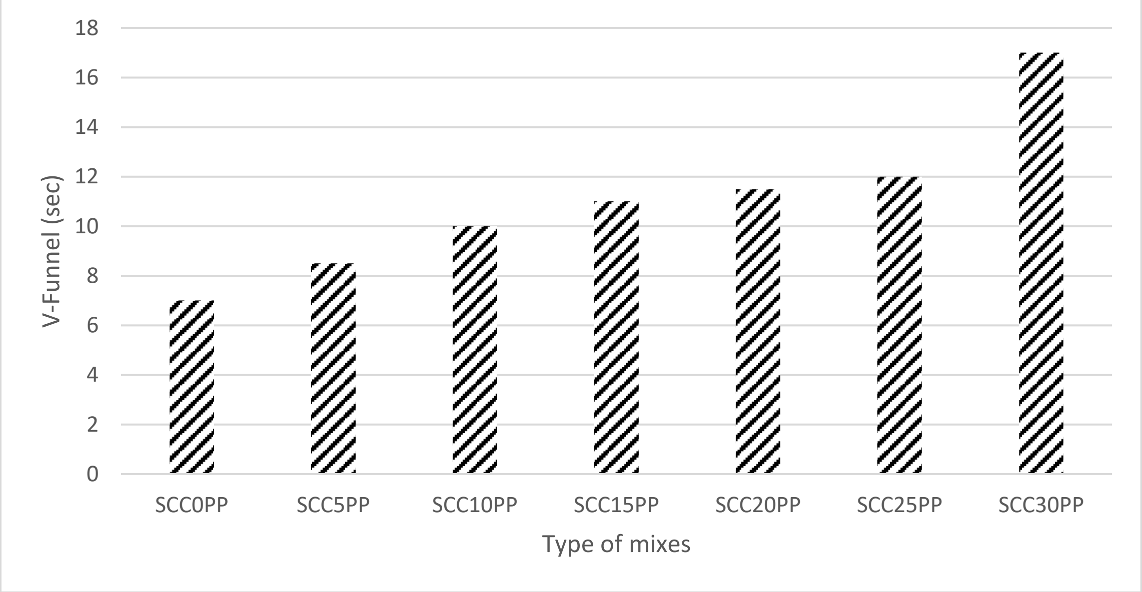

Figure 4.3: Effect of Substituted PPWP to Coarse Aggregate on Viscosity of SCC Mixes.

4.3 Effects of PP Waste Plastics on Compressive Strength

Compressive strength test results are illustrated in Table 4.2 and drawn in Figure 4.4. In addition, Figure 4.5 below shows the percentage loss of f_c compared to the control.

As is shown in the table and figures below, using PP as a 5 % replacement resulted in the highest value of f_c (58.57 MPa), and the percentage change relative to the control was 1.77 %. Conversely, when PP was used at a high level (25 %), it resulted in the lowest value of f_c (51.5MPa) and the highest percentage loss compared to the control (13.6 %). This implies that when the proportion of PP replacement increases, the f_c value goes down because PP light weight aggregate has a lower strength than natural coarse aggregate. Thus, PP light weight aggregate could not improve the strength of concrete when the compressive load was applied. It also caused a separation between the concrete materials, which explains the decrease in f_c values when the proportion of PP replacement increased.

Table 4.2: Changing of Compressive Strength Values

Type of mixes	Compressive strength (MPa)	Load (KN)	% Decreament in f_c
0%PPC	59.63	1350.00	0.00
5%PPC	58.57	1319.67	1.77 %
10%PPC	53.80	1210.33	9.77 %
15%PPC	53.30	1196.70	10.61 %
20%PPC	52.90	1192.00	11.20%
25%PPC	51.50	1185.00	13.60%

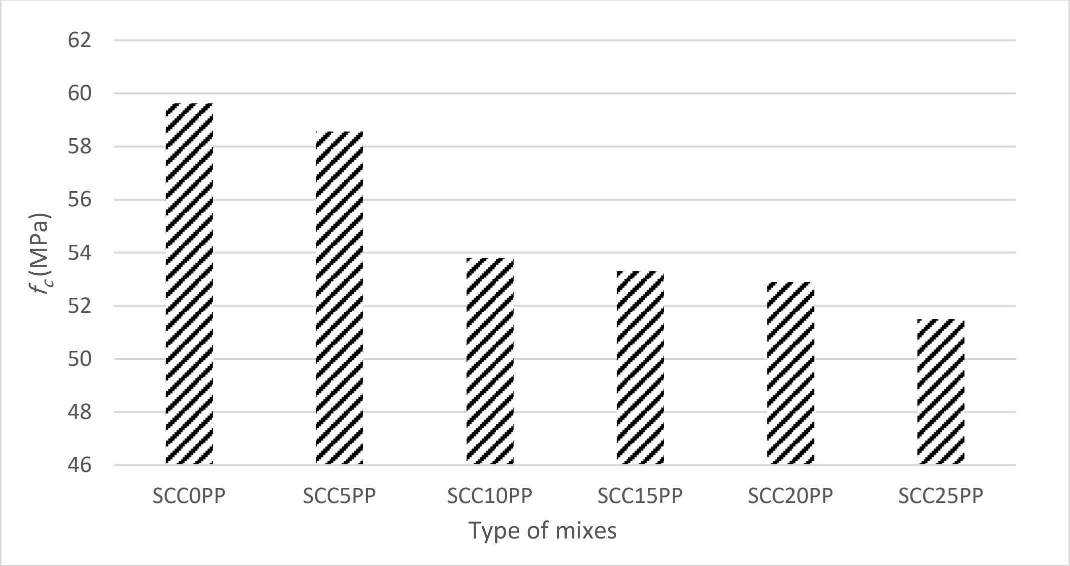

Figure 4.4: Effect of PP Waste Plastic Substitution to Coarse Aggregate on f_c.

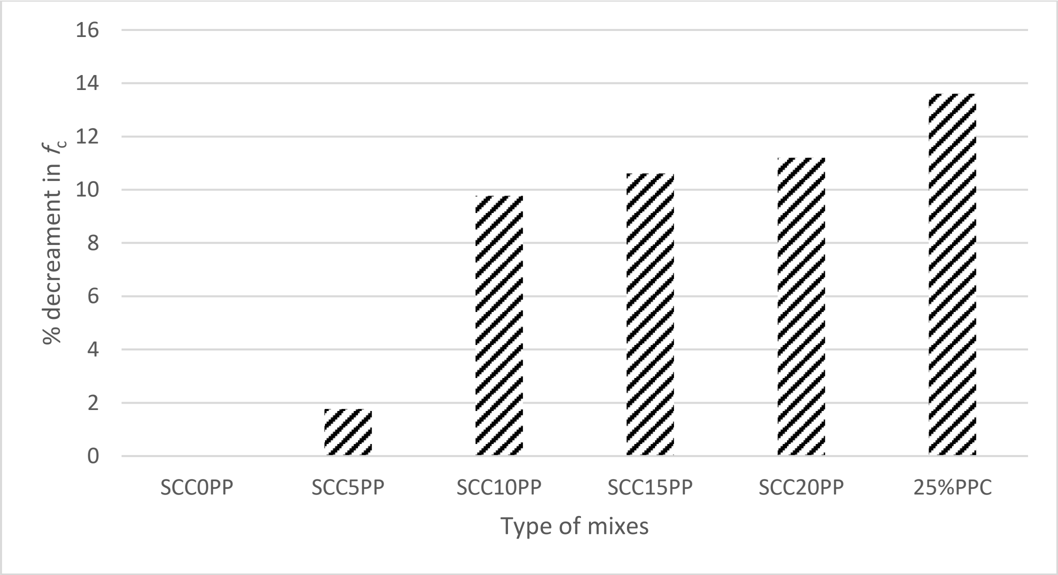

Figure 4.5: Effect of PP Waste Plastic Substitution to Coarse Aggregate on f_c Decreament

4.4 Effects of PP Waste Plastics on Splitting Tensile Strength

The test was conducted to prove the changes in the splitting strength of the specimens containing PP light weight aggregate compared to control (without PP). The test results are illustrated in Tale 4.3 and drawn in Figures 4.6 and 4.7 below.

In general comparison of the figures, it can be stated that the values of f_t were reduced when the proportion of PP replacement increased. This might be due to the weaker Interfacial Transition zone (ITZ) between PP light weight aggregate and the matrix, when compared with the ITZ between crusher natural coarse aggregate and the matrix. As a result, there was a reduction in the splitting strength. The control specimen without PP gives the highest value of ft. In addition, the lowest value of f_t was 3.696 MPa at SCC25PP, with a higher change when compared to the control (26.006 %).

Table 4.3: Changing of Splitting Tensile Strength Value

Type of mix design	Splitting tensile strength (MPa)	Load (KN)	% Decrement in f_t, compared to control
0%PPC	4.995	156.93	0.00
5%PPC	4.685	147.20	6.20 %
10%PPC	4.417	135.93	11.57 %
15%PPC	4.169	131.00	16.53 %
20%PPC	3.967	124.63	20.58 %
25%PPC	3.696	116.10	26.06 %

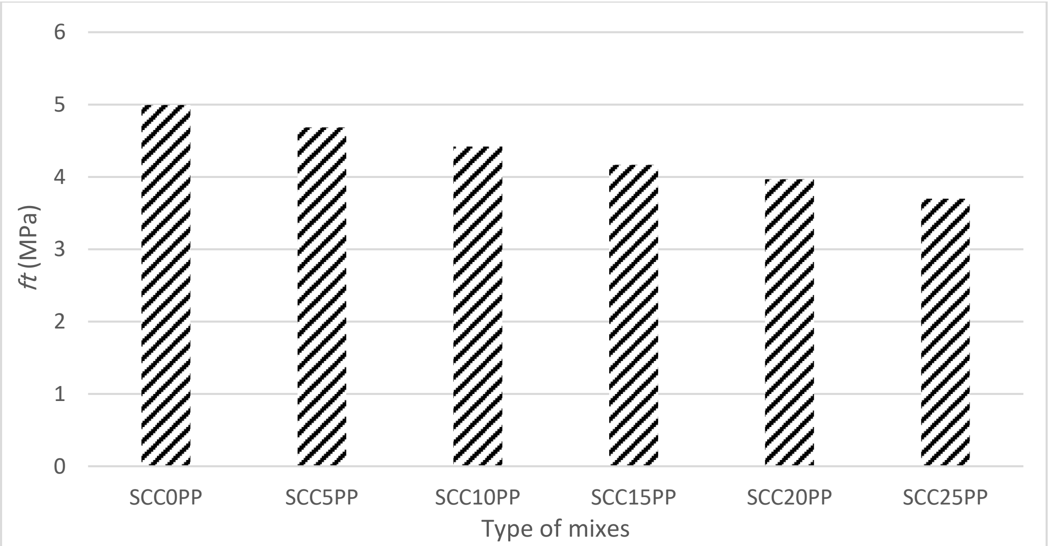

Figure 4.6: Effect of PP Waste Plastic Substitution to Coarse Aggregate on f_t

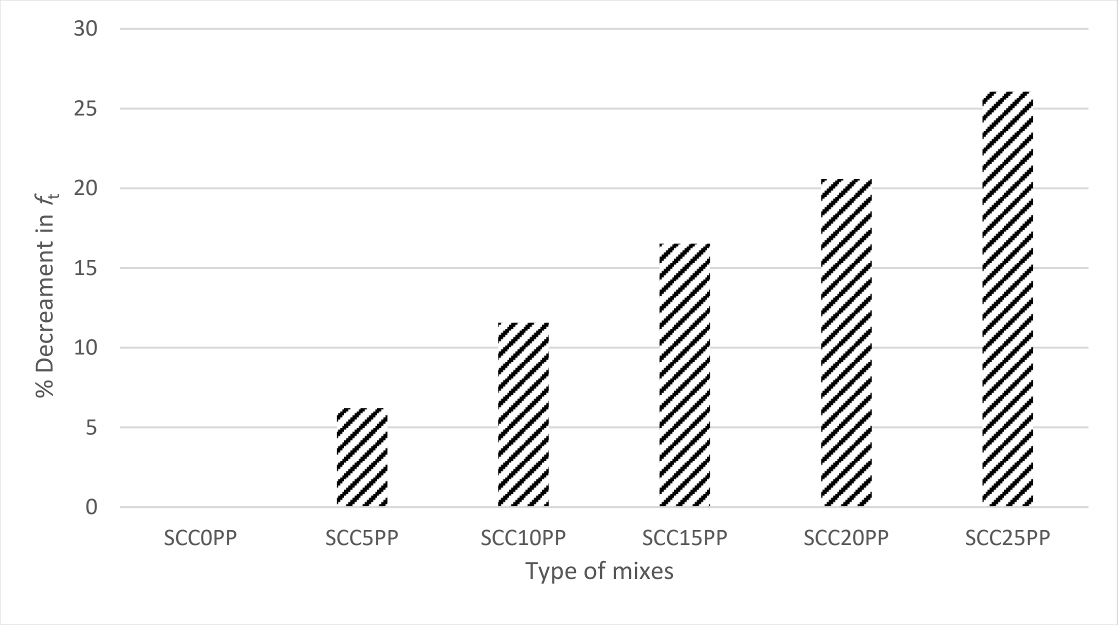

Figure 4.7: Effect of PP Waste Plastic Substitution to Coarse Aggregate on f_t Decrement.

4.5 Effects of PP Waste Plastics on Flexural Strength and Toughness

According to previous study, all of the specimens ruptured at two points. The test results of the maximum force on the specimen and the calculation of f_f are shown in Figure 4.8 below.

Flexural strength (f_f) values were calculated using the following equation:

$f_f = \frac{\mathbf{3 \times P \times L}}{\boldsymbol{bd}\mathbf{^\wedge 2}}$ **;**

Where:

- f_f: flexural strength (MPa)
- P: maximum applied load (kN)
- L: material span length points in the test setup (mm)
- b: width of the material specimen (mm)
- d: average depth of the specimen (mm)

As Figure 4.8 show, when the percentage of PP replacement increased from 5 % to 25 %, there was an improvement in f_f, which increased from 11.493 MPa to 14.589 MPa respectively. This is because when PP aggregates are added to the SCC mixes, they become viscous, which makes specimens more flexible under load, thus increasing f_f.

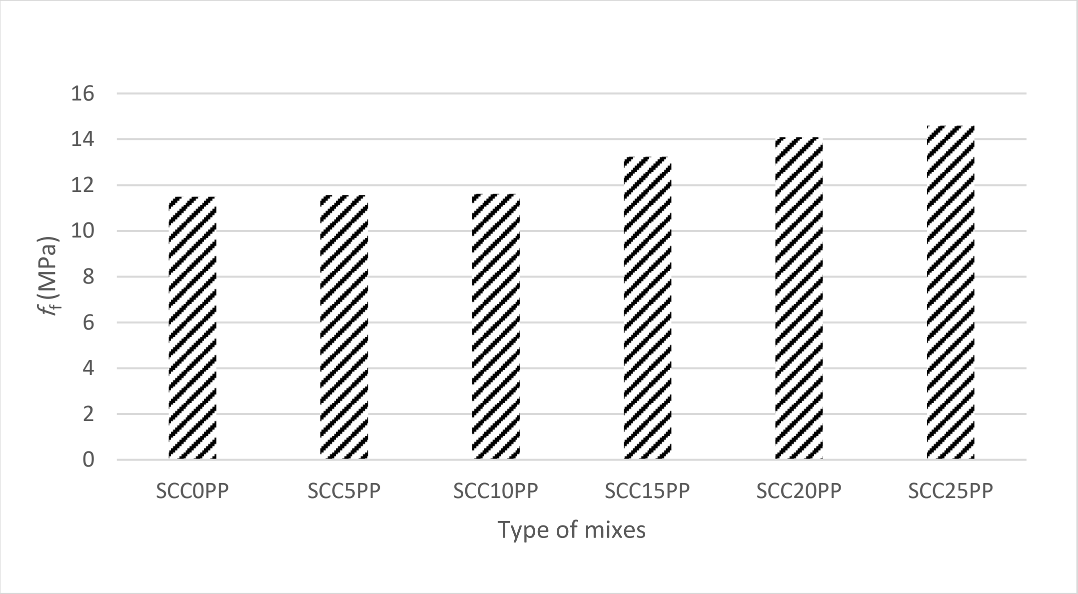

Figure 4.8: Effect of PPWP Substitution to Coarse Aggregate on f_f

It can be seen from the comparisons shown in the figure that all specimens containing PP from 0 % to 25 % have ductility but with different toughness areas. In addition, Figure 4.9 shows that the toughness area increased when the percentage of PP aggregate inside the specimens increased. The highest toughness area was at 25% of PP replacement. That is because when PP was added to SCC mixes, makes specimens more tough in terms of load deflection. Results of the relevant toughness test are drawn in Figure 4.9 below.

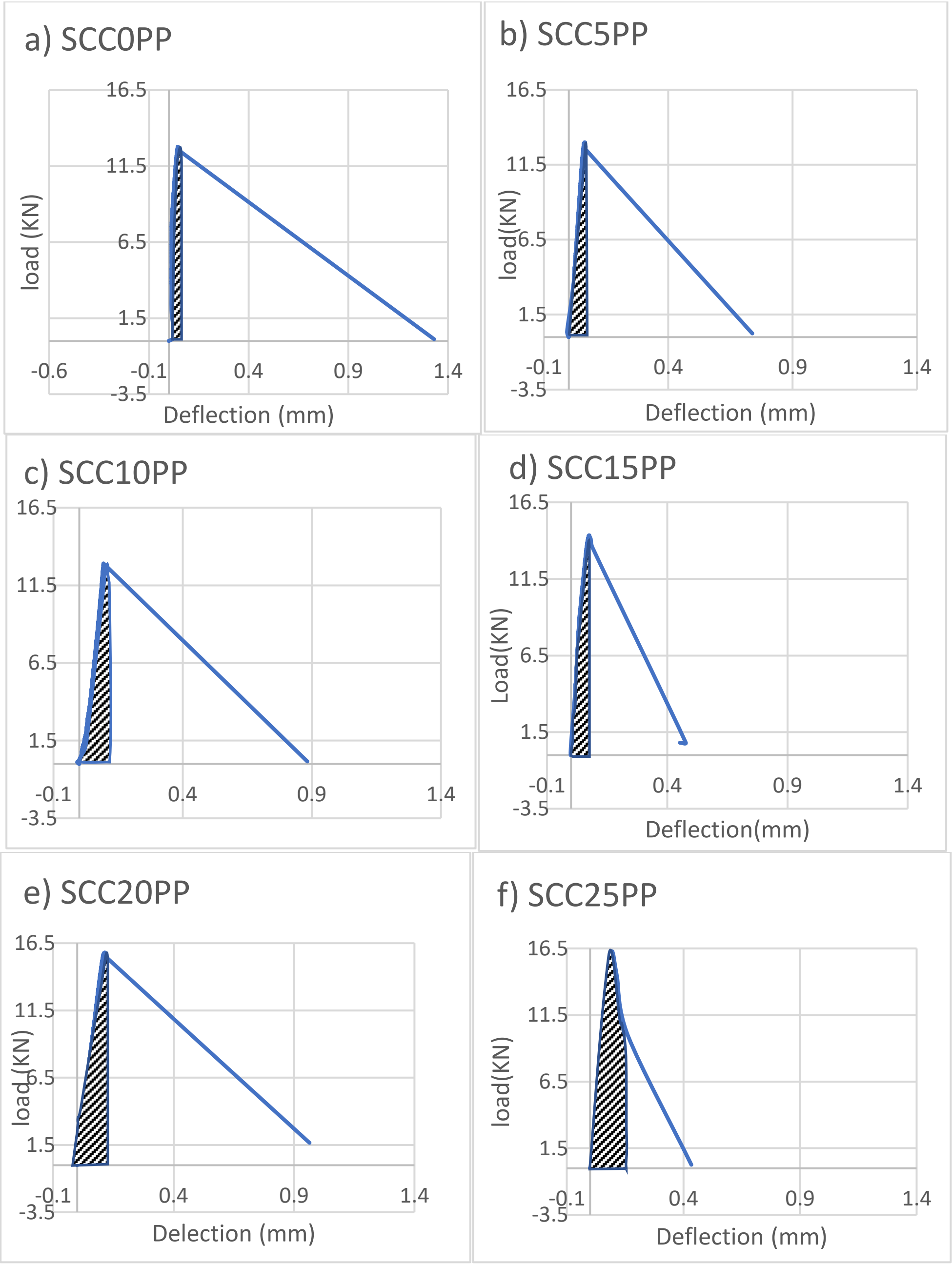

Figure 4.9: Effect of PP Waste Plastic Substitution to Coarse Aggregate on Load Deflection Diagram.

4.6 Relationships between the Compressive Strength and other Mechanical Properties

In order to observe the relationship between f_c and the other two mechanical properties (ft strength and f_f) and the replacement of natural coarse aggregate with PP Waste Plastic in SCC, the variation regression types of ft and f_f with f_c were calculated using models by specific relation factors R^2 (shown in Table 4.4 and Table 4.5 below). As is shown in the tables, R^2 was calculated according to the regression type with the best relation indicated. In addition, it can be seen from Figure 4.10 that, when f_c decreased, splitting strength also decreased, while Figure 4.11 shows a negative relation between f_c and f_f: when f_c decreased, f_f increased.

Table 4.4: Relationship between ft and f_c for PP Replaced SCC Mixes

Concrete type	Regression Type	Equation	R^2
PPSCC	Exponential	$y = 0.7755e^{0.0312x}$	0.8801
	Linear	$y = 0.1359x - 3.1448$	0.8971
	Logarithmic	$y = 7.5942\ln(x) -26.093$	0.9026
	Polynomial (2nd order)	$y = -0.0166x^2 + 1.9845x - 54.561$	0.9338
	Power	$y = 0.004x^{1.7434}$	0.8868

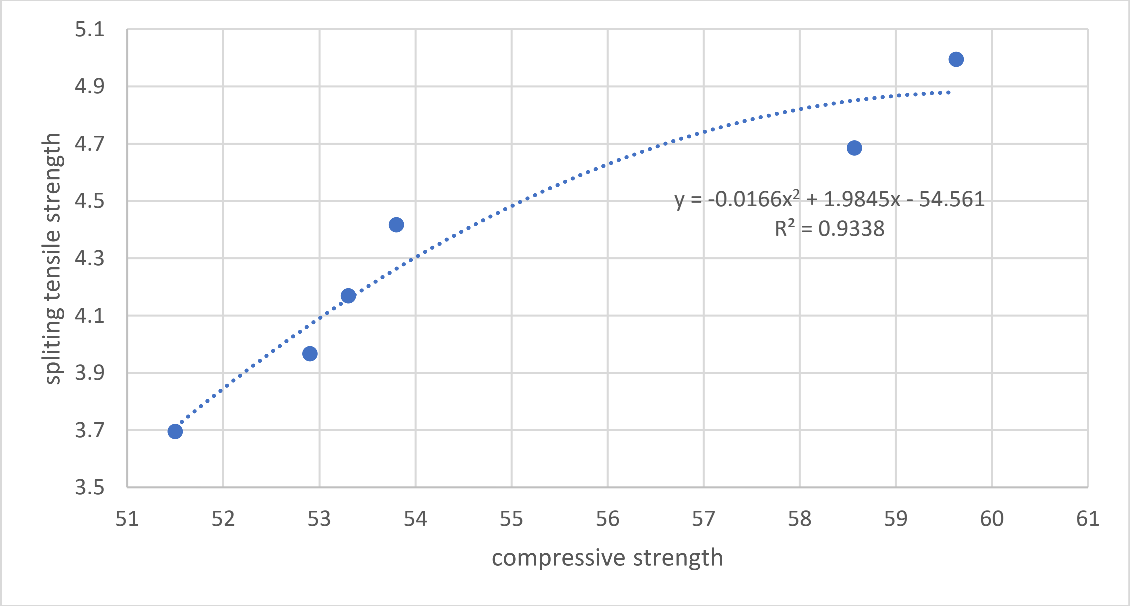

Figure 4.10: Relationship between ft and f_c in PP Replaced SCC Mixes

Table 4.5: Relationship between f_f and f_c for PP Replaced SCC Mixes.

Concrete type	Regression Type	Equation	R^2
PPSCC	Exponential	$y = 54.496e^{-0.027x}$	0.6635
	Linear	$y = -0.3399x + 31.438$	0.6583
	Logarithmic	$y = -19.08\ln(x) + 89.177$	0.6682
	Polynomial (2nd order)	$y = 0.1025x^2 - 11.777x + 349.54$	0.823
	Power	$y = 4910.5x^{-1.488}$	0.673

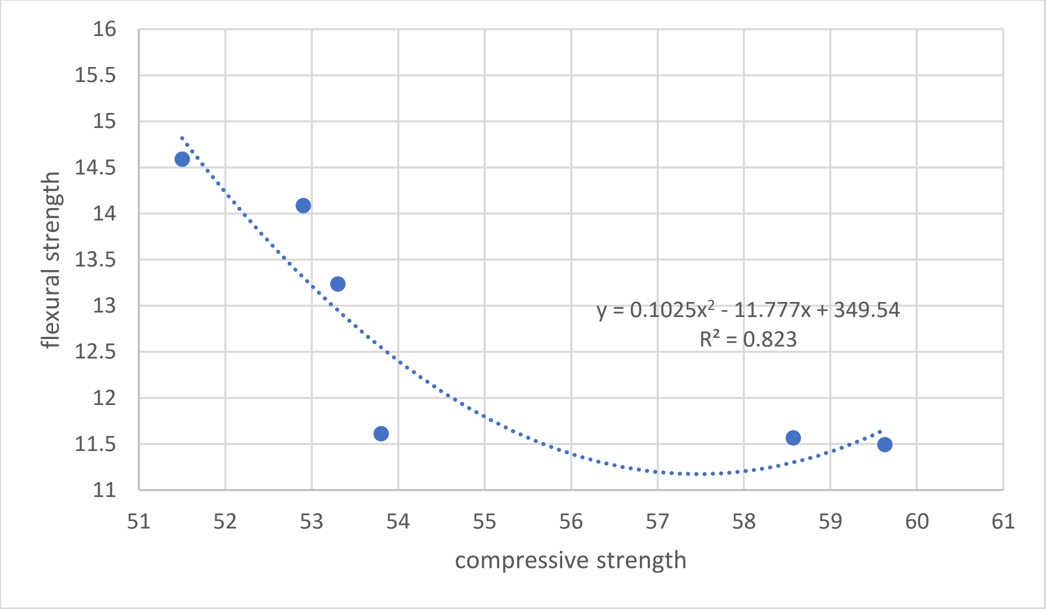

Figure 4.11: Relationship between f_f and f_c for PP Replaced SCC Mixes

4.7 Degradation Test against Heat at 100°C and 200°C

This test aims to measure the effects of the increased environmental temperature (100°C and 200°C) on deterioration, weight loss, f_c and ft in SCC mixes.

In order to achieve this, the weight, ultrasound readings, f_c and ft values were measured both before and after they were heated separately in the oven at 100°C and 200°C.

4.7.1 Surface Crack Detection of all Mixes both before and after Heating

As it is clear in Table 4.6 and Figure 4.12 below, the replacement of natural coarse aggregate with PP light weight aggregate in SCC mixtures, does not have any effect on the surface of the specimen. This is so because PP aggregate reduces the bonding between materials mixed inside specimen, which is not visible on the surface. On the other hand, heating those specimens at 100°C, which is lower than the melting point of polypropylene (150°C), caused small cracks on the surfaces of specimens (see Figure 4.13). The resulting cracks begin from 0.35 mm for 5% of PP replacement and increased to 0.80 mm when the percentage of PP replacement was increased to 25%. Additionally, when the specimens were exposed to heat at 200°C, which is higher than the melting point of polypropylene (150°C), the PP aggregate inside the specimens melted and produced big cracks on the surface of specimens (see figure 4.14). These cracks began from 0.9 mm for 5% of PP and increased to 1.88 mm at 25% PP replacement.

Table 4.6: Crack Widths on Specimen Surfaces before and after Heating

Type Of specimens	Width of crack (mm)		
	Before heating	After heating at 100 °C	After heating at 200 °C
SCC0PP	0 mm (NO crack)	0 mm (NO crack)	0 mm (NO crack)
SCC5PP	0 mm (NO crack)	0.35 mm	0.91 mm
SCC10PP	0 mm (NO crack)	0.42 mm	0.95 mm
SCC15PP	0 mm (NO crack)	0.44 mm	1.03 mm
SCC20PP	0 mm (NO crack)	0.59 mm	1.13 mm
SCC25PP	0 mm (NO crack)	0.80 mm	1.88 mm

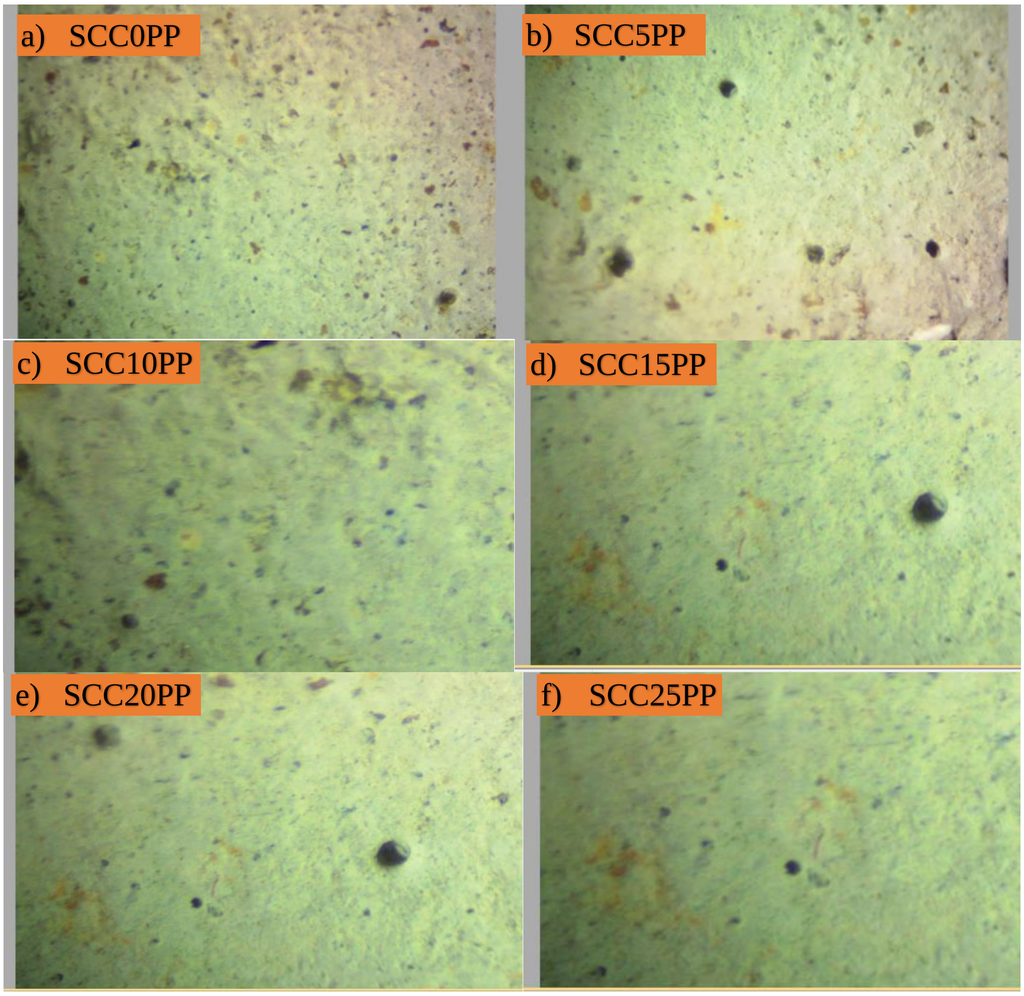

Figure 4.12: Surface of Specimens before Heating

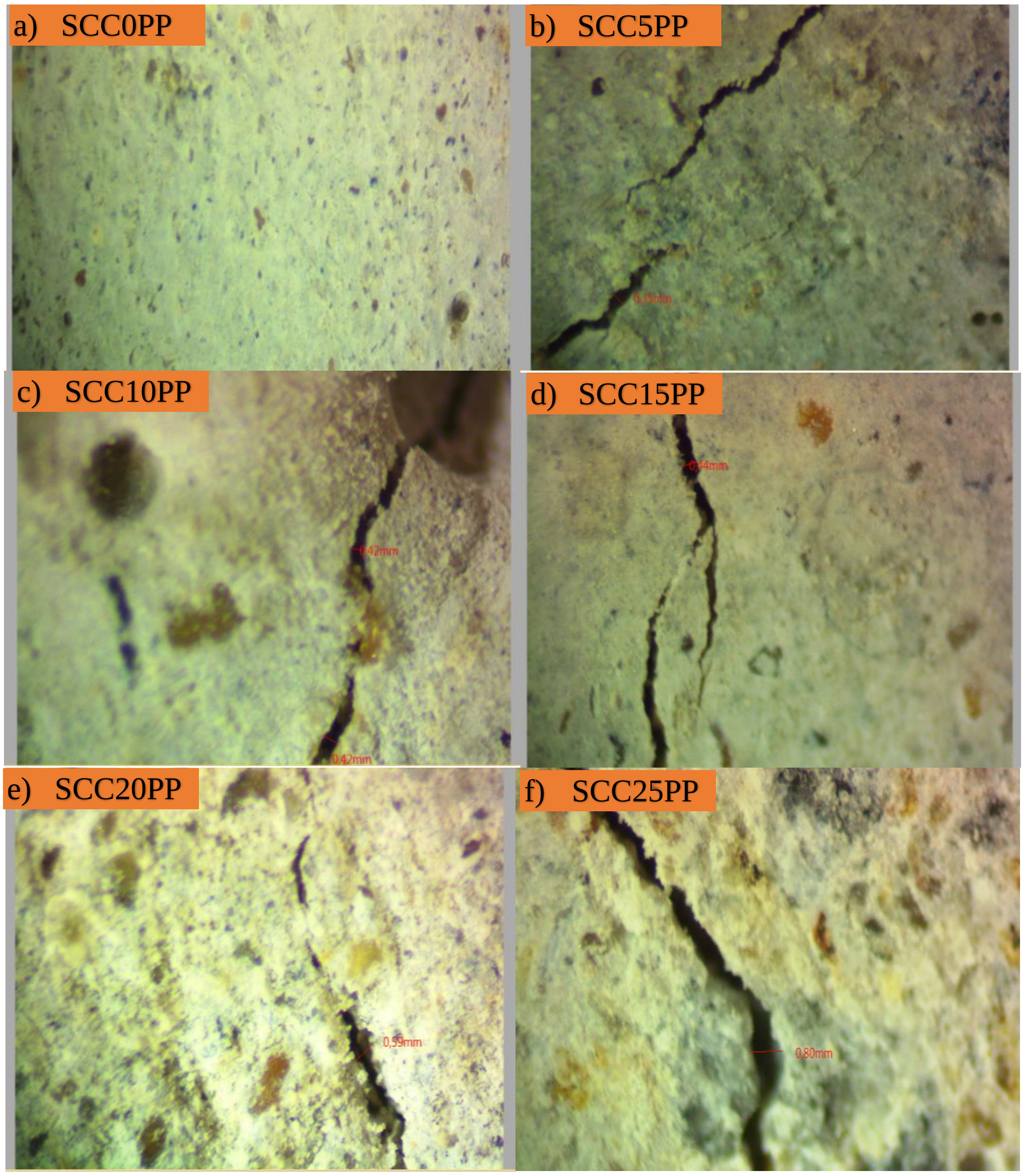

Figure 4.13: Surface of Specimens after Heating at 100 °C

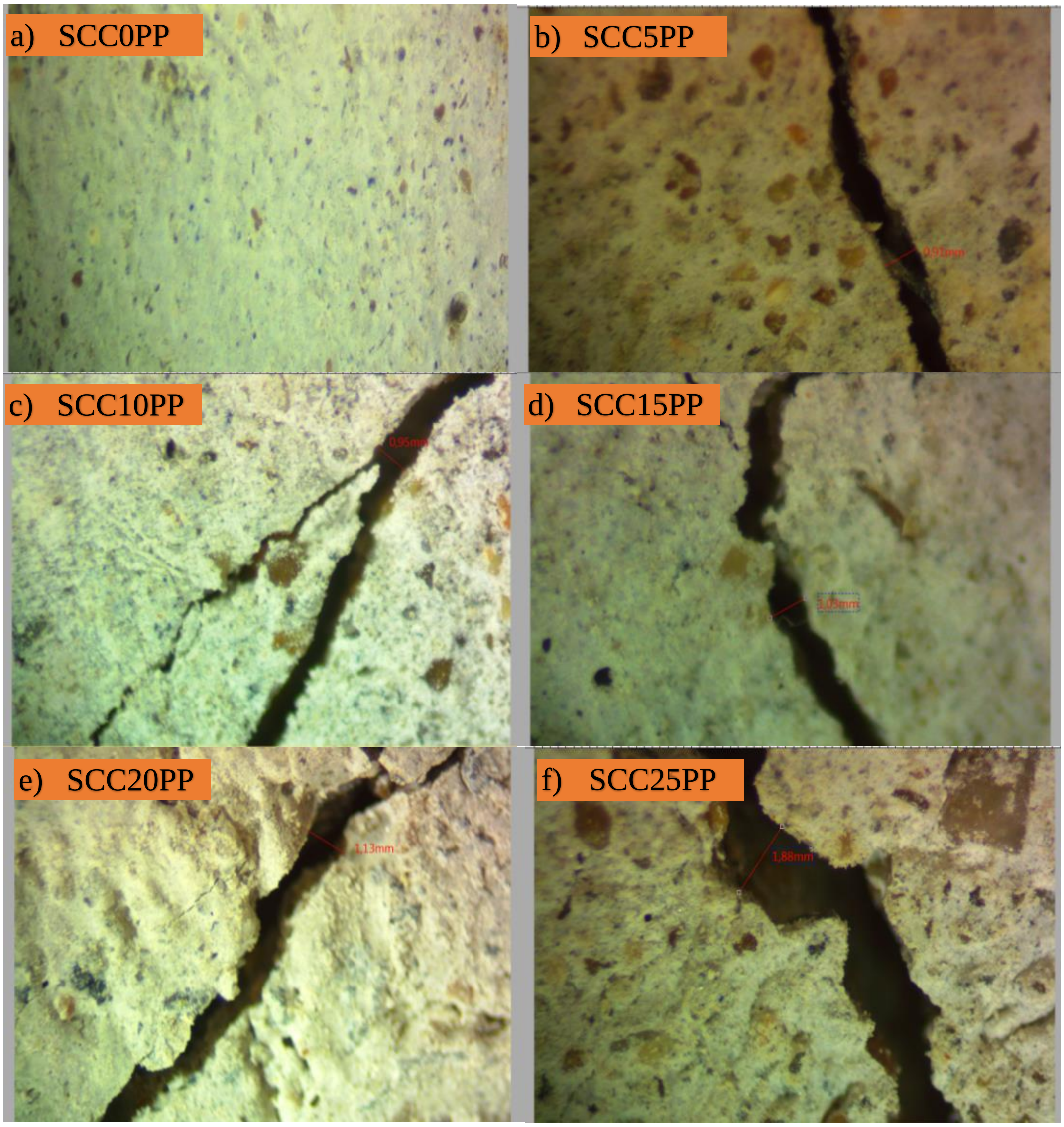

Figure 4.14: Surface of Specimens after Heating at 200 °C

4.7.2 Effects of PP Waste Plastics on Flexural Strength and Toughness

With a view to measuring the effects of different proportions (0, 5, 10, ,15, 20 and 25%) of PP replacement in SCC mixtures, and also the effects of the heat degradation test at two different temperature (100°C and 200°C) on the weight of specimens, ninety small cubes (100 mm) were weighed before and after heating.

As is shown in Table 4.7 and Figure 4.15 below, for 0% of PP replacement, the weight of specimens was 2.343 kg. This decreased to 2.301kg with the increase of the proportion of PP up to 25%. This change occurred because natural coarse aggregate was replaced by PP light weight aggregate, which caused a reduction in the weight of the specimens with every increase in the proportion of PP aggregate.

In addition, heating the specimens at 100°C caused the evaporation of some water inside the cubes, which resulted in a reduction in the weight of specimens from 2.327 kg for 5% replacement of PP to 2.153 kg for 25% of PPWP. After exposing the specimens to a heat of 200°C, the PP inside the cubes melted and lost some of its initial weight. This heating also caused a higher level of water evaporation from inside the cubes, which explains the high reduction in the weight of the specimens from 2.160 kg to 1.857 kg with the increase in the proportion of PPWP from 5% to 25% after exposure.

Table 4.7: Weight of Specimens before and after Heating.

Type of specimens	Weight of specimens (kg)		
	Before heating	After heating at 100°C	After heating at 200°C
SCC0PP	2.343	2.327	2.160
SCC5PP	2.339	2.322	2.151
SCC10PP	2.329	2.312	2.093
SCC15PP	2.315	2.296	2.011
SCC20PP	2.301	2.284	1.992
SCC25PP	2.174	2.153	1.857

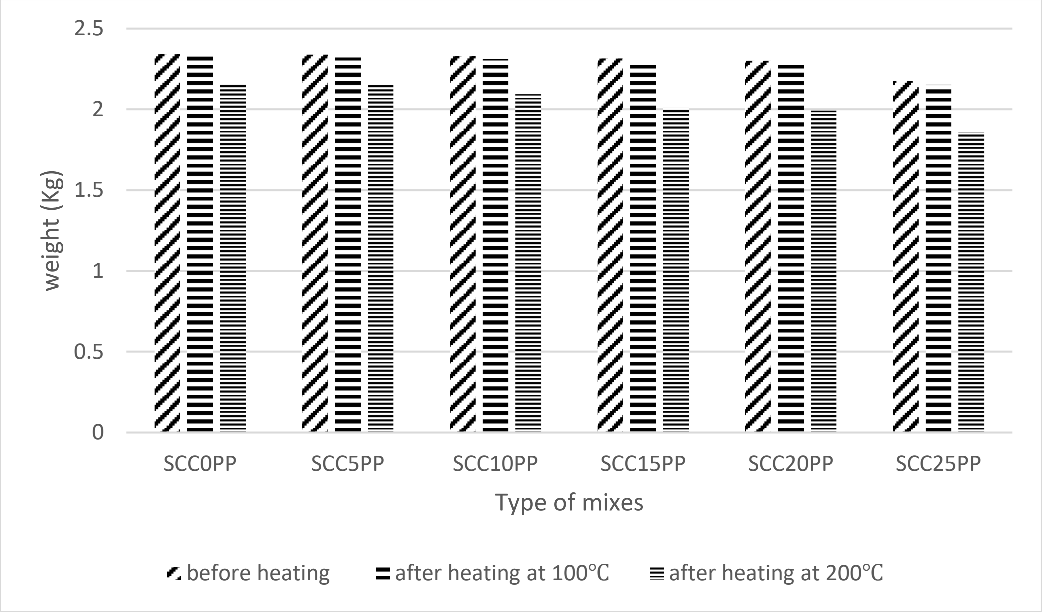

Figure 4.15: Weight of Specimens before and after Heating.

4.7.3 Effect of Degradation Test and Different PP Waste Plastic Proportions on the Ultrasonic Pulse Velocity of Specimens

The ultrasonic pulse velocity of specimens containing six different proportions of PPWP was measured before and after heating separately at 100℃ and 200℃. The results are illustrated in Table 4.8 and drawn in Figure 4.16 below.

As is shown in Table 4.8, by increasing the percentage of PPWP from 0% to 25%, the ultrasonic pulse velocity decreased slowly from 4.93km/sec to 4.78km/sec. This is because using PP light weight aggregate to replace natural coarse aggregate in SCC mixtures caused a reduction in the bonding between the materials mixed, which creates a void inside the specimens. On the other hand, exposing the specimens to a temperature of 100℃ caused microcracks in the specimens, which explains the reduction of ultrasonic pulse velocity from 4.5 km/sec for 0% PPWP to 3.33 km/sec for 25% of PPWP.

In addition, it can be seen that there was a higher reduction in ultrasonic pulse velocity after heating at 200℃. For example, while pulse velocity decreased from 4.82 km/sec to 4.00 km/sec at 0% PPWP, it continued decreasing up to 2.26 km/sec for 25% PPWP. This occurred because when specimens were heated at a high temperature (200℃), the PP aggregate inside the specimens melted and produced big cracks in the specimens.

Table 4.8: Pulse Velocity Values before and after Heating Test.

Type Of Specimens	Before heating		After heating at 100 ℃		After heating at 200 ℃	
	Time (µs)	Pulse velocity (km/sec)	Time (µs)	Pulse velocity (km/sec)	Time (µs)	Pulse velocity (km/sec)
SCC0PP	20.75	4.82	22.22	4.50	24.95	4.00
SCC5PP	20.90	4.78	23.75	4.21	26.46	3.78
SCC10PP	21.23	4.71	24.26	4.12	41.5	2.40
SCC15PP	22.2	4.50	27.3	3.66	40.1	2.49
SCC20PP	23.75	4.21	28.9	3.46	41.83	2.39
SCC25PP	24.26	4.12	29.96	3.33	44.16	2.26

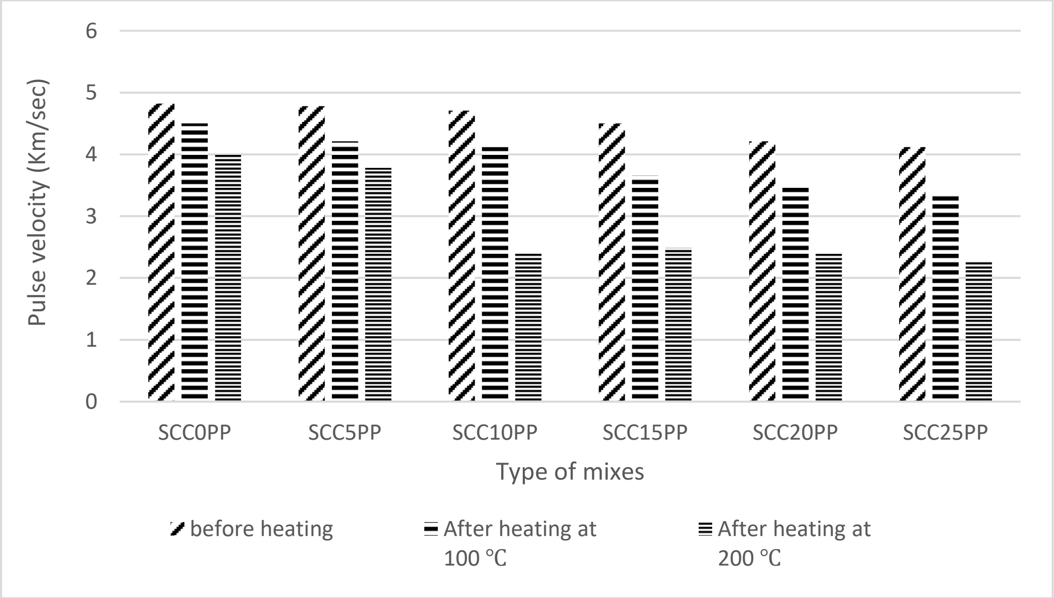

Figure 4.16: Ultrasonic Pulse Velocity before and after Heating Test.

4.7.4 Effect of Degradation Test against Heating on the Compressive Strength

The f_c was tested before and after heating specimens containing six different PPWP proportions at two different temperatures (100℃ and 200℃). Test results are illustrated in Table 4.9 and drawn in Figure 4.17 below.

As is shown in Table 4.9, specimens before heating have the highest value of f_c compared to others after heating. Furthermore, specimens exposed to a temperature of 100℃ have a higher f_c value than those exposed to 200℃. For example, the f_c for 0% PPWP was 75.52 MPa, which decreased to 67.35 MPa after heating at 100℃, and then to 61.3 MPa after heating at 200℃. This decline in f_c can be explained by the microcracks in the specimens resulting from the heating. In addition, heating specimens at 200℃, caused the melting of PP which is produced big cracks within samples, this can explain the further reduction in f_c for specimens exposed to 200℃.

Table 4.9: Compressive Strength Values before and after Heating Test.

Type Of Specimens	Before heating		After heating at 100 ℃		After heating at 200 ℃	
	Load (KN)	f_c (MPa)	Load (KN)	f_c (MPa)	Load (KN)	f_c (MPa)
SCC0PP	755.2	75.52	673.5	67.35	613	61.3
SCC5PP	656.3	65.63	627.3	62.73	537	53.7
SCC10PP	606.3	60.63	579	57.9	465	46.5
SCC15PP	584.3	58.43	568.5	56.85	375.3	37.53
SCC20PP	523.6	52.36	493.3	49.33	317.3	31.73
SCC25PP	475.3	47.53	433.5	43.35	245.7	24.57

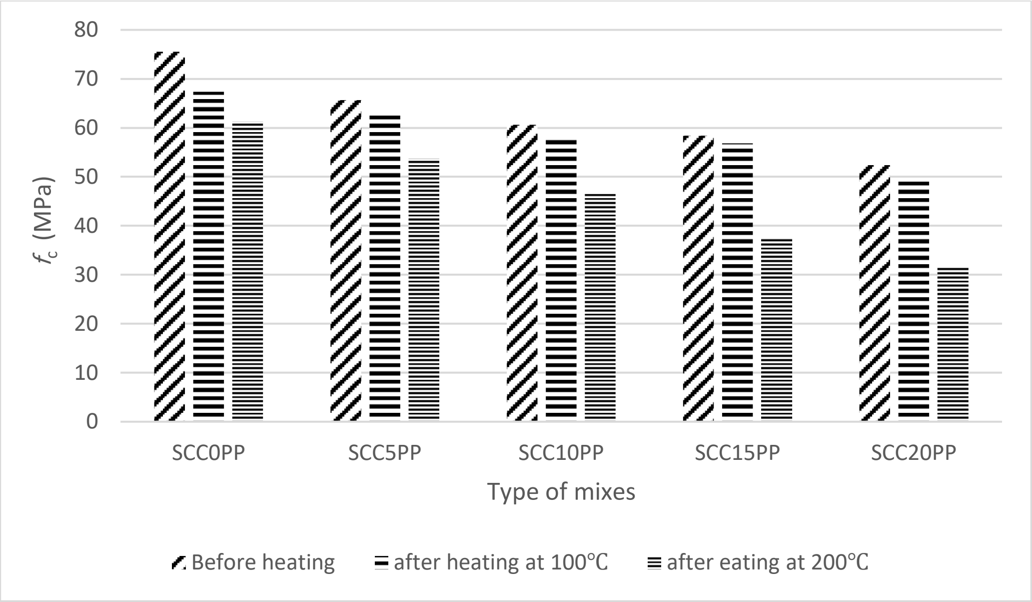

Figure 4.17: Compressive Strength before and after Heating Test.

4.7.5 Effect of Degradation Test against Heating on the Splitting Tensile Strength of Specimens

The f_t of samples including different PP waste plastic proportions was tested before and after heating those samples separately at two different temperatures (100℃ and 200℃). The results obtained are demonstrated in Table 4.10 and drawn in Figure 4.18 below.

As is clear in Table 4.10, the specimens before heating have the highest value of *ft* compared to other specimens exposed to temperatures of 100℃ and 200℃. Additionally, when the temperature increased from 100℃ to 200℃, the *ft* decreased. For example, at 25 % PP and before heating, the splitting strength was 3.211 MPa. This decreased to 2.535 MPa after heating at 100 ℃ then to 2.296 MPa after heating at 200℃. This reduction in the *ft* of heated specimens can be attributed to the evaporation of water from inside the specimen concrete. This results in a buildup of pore pressure and the propagation of microcracks within the concrete. Furthermore, when the specimens were heated at 200℃, which is higher than the melting point of polypropylene, the melting of the PP aggregate inside the specimens produced a big crack in the specimens, which is responsible for the higher reduction in the splitting strength after heating at 200℃.

Table 4.10: Splitting Tensile Strength Values before and after Heating Test.

Type Of Specimens	Before heating		After heating at 100 ℃		After heating at 200 ℃	
	Load (KN)	*ft* (MPa)	Load (KN)	*ft* (MPa)	Load (KN)	*ft* (MPa)
SCC0PP	68.11	4.339	66.8	4.255	59.5	3.791
SCC5PP	64.05	4.075	57.45	3.655	41.86	2.673
SCC10PP	60.32	3.837	52.35	3.33	37	2.352
SCC15PP	56.80	3.622	44.7	2.852	36.23	2.296
SCC20PP	54.04	3.446	44.7	2.851	32.35	2.154
SCC25PP	49.71	3.211	39.25	2.535	31.29	2.085

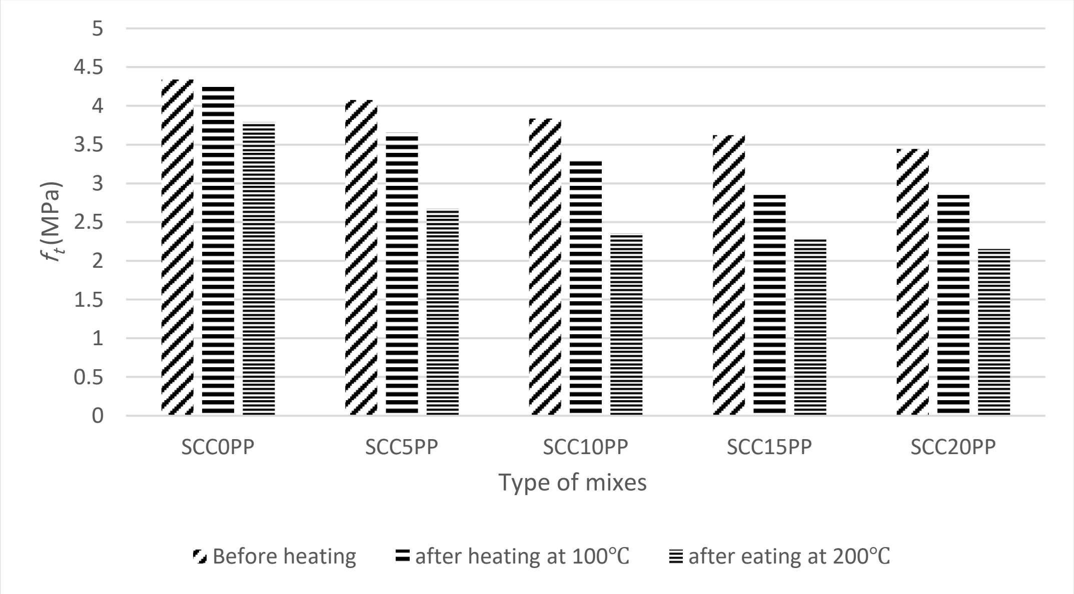

Figure 4.18: Splitting Tensile Strength before and after Heating Test.

Chapter 5

CONCLUSIONS

5.1 Conclusions

In this study, 0.45 w/b SCC mixes incorporated with PP waste plastics as a replacement to natural coarse aggregate in six different percentages (0, 5, 10, 15, 20 and 25%).The following conclusions were reached based on the results of the tests conducted on both fresh and hardened concrete over the course of the study.

1. As the percentage of PP replacing natural coarse aggregate increased from 0% to 25%, the workability of the fresh concrete decreased.
2. At 30% of PP replacement, even the proportion of Glenium was increased from 1.75% to 3%, SCC workability requirements were not satisfied.
3. Increasing the percentage of PP from 5% to 25%, caused a decrease in both f_c and f_t. The lowest f_c and f_t values are obtained when highest level (25%) of PP were replaced to coarse aggregate produced the lowest values of f_c (51.5MPa) and f_t (3.696MPa).
4. Replacing natural course aggregate with PP light weight aggregate, decreased the weight, f_c and f_t and ultrasonic pulse velocity readings of the specimens. Oppositely f_f increased with increased PP replacement.
5. Heating the specimens at a temperature of 100°C had a negative effect on f_c, f_t, weight and ultrasonic pulse velocity. In addition, when the temperature was increased up to 200°C, those properties diminished further with their lowest values at 25% of PP replacement.

6. In terms of f_f, increasing the percentage of PP waste plastic resulted in an improvement in f_f. The highest value of flexural strength (14.589MPa) was at SCC25PP.
7. Using PP aggregate as a replacement volume of natural coarse aggregate can increase flexibility and produce some ductility in beam specimens, which improved parallel to increases in the proportion of PP.

5.2 Recommendation for Future Studies

1. Using PP aggregate as a replacement by the volume, as opposed to the weight, of natural coarse aggregate in SCC mixes with different w/b ratios.
2. Using high percentages (up to 80%) of PP as a replacement to natural coarse aggregate, in order to measure their effect on the physical and mechanical properties of normal concrete.
3. Try to measure the effect of different proportions of PPWP replacement of natural coarse aggregate on the durability aspects of concrete, such as freezing and melting, shrinkage and permeability tests.

4. Try to measure the effect of different proportions of PPWP replacement of natural coarse aggregate on the durability aspects of concrete, such as freezing and melting, shrinkage and permeability tests.

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