Effect of Polystyrene as a Partial Replacement of Normal Coarse Aggregate on Fresh and Hardened Properties of Self-Compacting Concrete

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ABSTRACT

This experimental research covers studying fresh and some mechanical properties of self-compacting concrete (SSC) incorporating Polystyrene beads (PS) as a partial substitution with crushed coarse aggregate. Waste materials such as Polystyrene is difficult and not cost effective to recycle or to store. By recycling this material in concrete in order to produce a lighter weight concrete, will reduce the pollution burden that harms the environment and the landfill cost.

This experimental study evaluates the effect of five different percentages of PS as a replacement by volume of normal coarse aggregate namely 0, 20, 40, 60 % with 1.75 % Gelnium (G), 60 % with 1.5 % G) with 0.45 water-binder ratio (w/b) on the mechanical and physical properties of concrete. For all SCC concrete mixtures, 10 % micro-silica was added, by weight of the cement, as an addition. Two different amounts of superplasticizer (G) have been added to achieve the SSC fluidity, at 1.5% and 1.75% of the cement weight. For example, both 1.5% and 1.75% of the superplasticizer were used in the 60% aggregate replaced sample. For this aim, workability (assisted by L-Box test, V-funnel test, Slump Flow test), compressive strength, splitting tensile strength, degradation test (assisted by UPV, mass loss, compressive strength and splitting tensile strength), flexural strength and toughness. In general, the test results illustrate that when the percentages of Polystyrene increases, all values in the tests reduces compared with the control specimens.

Keywords: Workability, Compressive Strength, Splitting Tensile Strength, Degradation Test, Ultrasonic Pulse Velocity (UPV), Density, Flexural Strength and Toughness.

ÖZ

Bu deneysel araştırmanın amacı, kendiliğinden yerleşen beton (KYB)'da, normal agreganın atık Polistiren boncuklar (PS) ile kısmi olarak yer değiştirmesi neticesinde KYB'nun işlenebilirlik ve mekanik özelliklerinde oluşan farklılıkları tesbit etmektir. Polistiren gibi atık maddeleri, geri dönüştürmek veya depolamak zordur ve de ayrıca ekonomik değildir. Daha hafif bir beton üretmek için bu malzemeyi betonda, amaca göre belirli miktarlarda agrega yerine kullanmak, yani atık malzemeyi geri dönüştürmek, çevreye ve depolama maliyetine zarar veren kirlilik yükünü azaltacaktır.

Bu deneysel çalışmada, PS atık malzemesi iri agrega yerine 5 farklı yüzde oranında, yani % (0, 20, 40, 1.5G60, 1.75G60) oranlarında iri agrega yerine 0.45 s/ç oranında üretilmiş olan KYB'na katılmıştır. Ayni zamanda üretilmiş olan tüm tip betonlara çimento ağırlığının %10'u kadar silis dumanı katılmıştır. KYB akışkanlığını sağlamak için, yine çimento ağırlığının %1.5 ve %1.75 olmak üzere iki farklı miktarda süperakışkanlaştırıcı katılmıştır. Örneğin %60 agrega yerdeğişim numunesinde hem %1.5 hem de %1.75 akışkanlaştırıcı kullanılmıştır. Tüm numuneler için taze ve sertleşmiş beton deneyleri yapılmıştır. İşlenebilirlik deneyleri sırasıyla L-Box deneyi, V-hunisi ve çökme testi olarak verilebilir. Mekanik deneyler ise; basınç dayanımı, çekme dayanımı, eğilme dayanımı ve tokluk olarak sıralanır. Degradasyon deneyi (UPV) neticesinde, kütle kaybı ve dayanım kayıpları tesbit edilmiştir. Genel olarak, deney sonuçları, Polistiren yüzdeleri arttığı zaman, testlerdeki tüm değerlerin kontrol numuneleri ile karşılaştırıldığında azaldığını göstermektedir.

Anahtar Kelimeler: Kendiliğinden yerleşen beton (KYB), Polistiren boncukları, İşlenebilirlik, Basınç mukavemeti, Yarma mukavemeti, Sıcaklık etkisi, Ultrasonik deneyi (UPV), Yoğunluk, Eğilme dayanımı ve Tokluk.

DEDICATION

To all my family

I would like to thank

My lovable Friends, Mr. Mohamad Al Zohby, Mr. Fiyad Hamze, Mr. Alaa Hamze and Mr. Abdulhadi Al Zaylaa

who supported me all the time

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LIST OF ABBREVIATIONS

Ca	Coarse Aggregate
Fa	Fine Aggregate
G	Gelnium
LWASCC	Lightweight Aggregate Self-Compacting Concrete
PAC	Polystyrene Aggregate Concrete
PS	Polystyrene
PW	Plastic Waste
SCC	Self-Compacting Concrete
SF	Silica Fume
SG	Specific Gravity
Wa	Water Absorption
W/b ratios	Water Binder Ratio

Chapter 1

INTRODUCTION

1.1 Background of the Research

One of the most commonly used material in construction is concrete. It is made up of cement, water, and fine and coarse aggregate. However, some special chemical and mineral admixtures are incorporated into concrete to achieve special desired characteristics. Lightweight concrete has many applications in modern construction (K. G. Babu et al., 2003) such as decks on long span bridges , insulation of water pipes, covering for architectural purposes and heat insulation on roofs. The use of lightweight concrete has become very common, thanks to its multiple advantages which include its load-bearing element as a result of the lower density elements and corresponding size reduction of the foundation.

A major part of the global environmental crises is recycling of waste materials. PW account for approximately 10 % of the 1.3 billion tons of global public waste (GMW), and it is predicted to be around 2.2 billion tons by 2025 (Hoornweg et al., 2012). Countries with high recycling rate recycle only about 50% of PW which are mostly developed countries, and 90% of PW end up in landfills in most developing countries (Gourmelon, 2015), compounding to the already extreme environmental pollution. The inert and hydrophobic nature of PW (Scott, 2000) makes it a major component of land and water pollutant (Thompson et al., 2009). Consequently, various methods aimed at recycling PW have emerged, namely: PW-to-fuel via pyrolysis (Wong et al., 2015), PW-to-Energy through incineration (Ouda et al., 2016), and PW as a supplementary material in manufacturing, construction and building.

Polystyrene is a type of plastic classified as artificial lightweight aggregate. It is a common plastic in world, which contributes a significant percentage of the PW, with a production of about several million tons per year. As mentioned earlier, PW is used as a supplement for construction and building, and current studies are focusing on using Polystyrene PW in concrete mixtures (Dalhat et al., 2017).

1.2 Problem Statement

The cement industry is responsible for around 10 % of gas waste in the atmosphere which leads to global warming and environmental disasters. The production of millions of tons of PW also contributes to the land pollution which intensifies the global warming (Mirzahosseini et al., 2015). The construction cost requirement for cement production increases the overall cost of construction projects, especially for projects were concrete is the main construction material and consumes high volume of concrete. All of the above mentioned problems (financial and environmental) require a more environmental friendly and cost effective replacement for the conventional concrete mixture.

1.3 Aim of the Research

In this thesis, we aim to analyze self-compacting concrete (SCC) properties by replacing fine and coarse aggregates with polystyrene from PW, and testing it at different levels (0 , 20 , 40 , 60 % with 1.75 % G and 60 % with 1.5 % G) with 0.45 water-binder (w/b) ratio on the physical and mechanical properties of SSC. This is of great significance because it is important to note the ratio and percentages of the combination that yields an improved physical, chemical and mechanical property.

Finding productive ways of utilizing continues supply of plastic PW preserves the environment. Using polystyrene as an aggregate for concrete mixtures serves construction industries and the environment in many ways. Firstly, the relief of the environment of polystyrene waste reduces environmental pollution which is a major environmental crises, consequently minimizing global warming effect. Secondly, the physical, chemical and mechanical properties that is likely to be achieved from using polystyrene as an aggregate improves the engineering of construction.

1.4 Methodology

To achieve the goals of this thesis, five different mixes were produced by substituting five different percentages (0, 20, 40, 60 % with 1.75 % G and 60 % with 1.5 % G) of Polystyrene (PS) with water/binder ratios (0.45). The mechanical behavior and physical properties of the concrete are investigated by performing the following tests: workability of fresh concrete, compressive strength, splitting tensile strength, weight loss of specimens before and after heat exposure, flexural strength, UPV and Degradation tests against heat.

1.5 Outline of the Thesis

To achieve the objectives of the thesis, it is designed as follows: the literature review is made in chapter 2, The thesis is organized as follows: chapter 2 presents the literature review, showing previous relevant studies on the properties of polystyrene and its effects as an aggregate in mixture concrete. Chapter 3 is the experimental work and complete details of the experimental procedures and methods performed using the appropriate standards. Chapter 4 presents the results of the experimental work with the discussion, analyzing them based on the published studies and achievements. Conclusions withdrawn from the experimental work and recommendation for future research studies are made in Chapter 5.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

The most used material for construction in the world is concrete, twice as much as other materials including wood, aluminum, steel and plastic. Therefore, improvement of mixture concrete contributes highly to the future of construction industry. The construction industry is in need of alternatives for mixture concrete. These alternatives needs to reduce cement consumption to make project cost effective and materials that are environmental friendly. In addition, materials that improve structural stability via improvement of chemical, physical and mechanical properties of concrete is imperative. An attractive technique for improving mixture concrete is replacement of fine and coarse aggregate with PW such as polystyrene. In addition, polystyrene has also been used as mixture in cement mortar (Ferrándiz-Mas et al., 2013).

To achieve improved thermal-insulation proportion in structures, (Ferrándiz-Mas et al., 2014) developed a lightweight cement mortar by combining expanded polystyrene and paper sludge ash, both of which are environmental pollutant. They produced low thermal and low density samples when compared to the controlled samples. Their results suggest the use of 60 % expanded polystyrene and 20 % paper sludge ash for plastering applications.

In using polystyrene as a component of mixture concrete, (Xu et al., 2012) tested the mechanical properties of using expanded polystyrene as an aggregate in concrete and bricks. In their experiment, they analyzed the mix proportion parameters using an optimization method known as Taguchi method. They used different proportion of expanded polystyrene per unit concrete (12 %, 20 % and 25 %) and w/c of (0.45, 0.50 and 0.55). They tested the compressive strength, density and stress-strain properties of the samples. Their test results suggest that expanded polystyrene has more effects on the lightweight concrete compressive strength than w/c ratio.

Advantages of using polystyrene in concrete mixture includes reducing porosity, reducing permeability and increasing durability (Dalhat & Al-Abdul Wahhab, 2017). (Amianti et al., 2008) used recycled expanded polystyrene with the aim of maintaining the visual aspect of concrete to be used on monuments and surfaces exposed to inclement weather. Expanded polystyrene is used to reduce fungus proliferation on concrete in addition to other advantages of using expanded polystyrene was achieved by developing a method for concrete impregnation with polystyrene (CIP).

2.2 Concrete Constituent Materials

The main constituent materials of concrete are water, cement, fine aggregate and coarse aggregates. Figure 1 shows a schematic of concrete main constituent materials. Mortar fills the gaps between coarse aggregate, and paste fills the gaps between fine aggregate. The paste is composed of a mixture of water, cement, minerals, chemical mixtures such as (viscosity modifier and water reducing admixtures) and entrained air (Li et al., 2017). For concrete improvement, recent research focuses on replacing the fine and coarse aggregate with other materials.

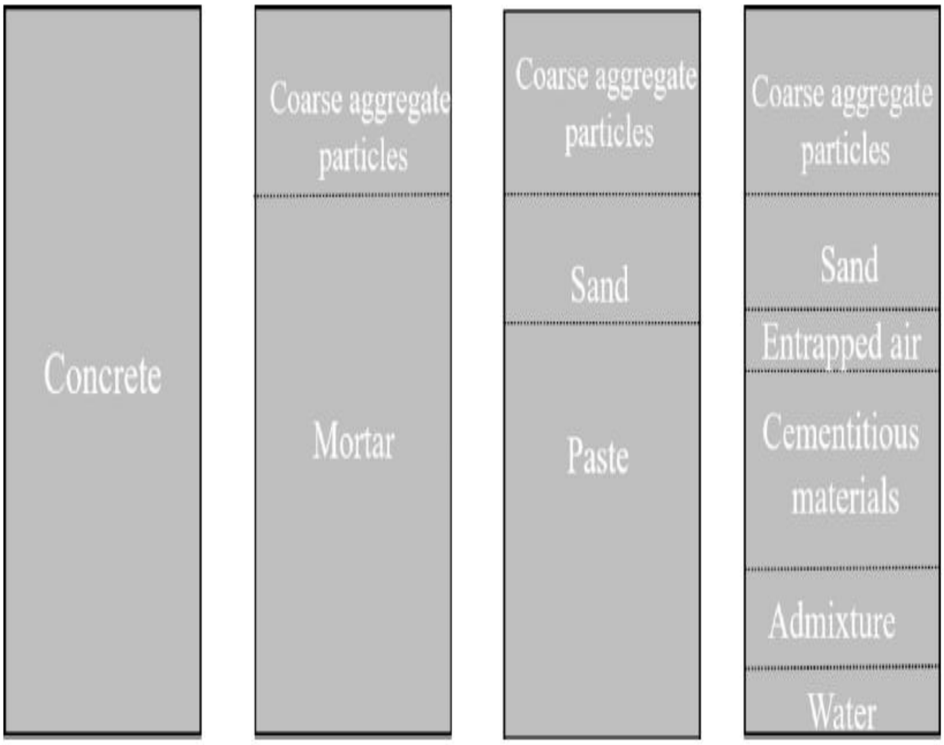

Figure 2.1: Schematic for Concrete Composition (Li et al., 2017)

(Ferrándiz-Mas & García-Alcocel, 2013) studied the influence of using expanded polystyrene in different forms on mortar durability. The microstructure was studied by using capillary water absorption, mercury intrusion, impedance spectroscopy and open porosity. They examined also the effects of freeze–thaw cycles, heat cycles and compressive strength. Their results suggest that using expanded polystyrene in mortar decreases capillary absorption coefficient when the mortar is subjected to heat cycles, a slight increment in the compressive strength of mortar was observed as a result of expanded polystyrene particles absorb partially the pressure of ice crystallization. Their conclusion was that the use of polystyrene improves durability of mortar~~,~~ which makes mortar having attained more sustainable masonry option, plaster mortar and stucco.

With the aim of the problem of solid waste and consequently environmental pollution and energy consumption, (Wang et al., 2012) developed cement mortar made with recycled high impact polystyrene. By replacing sand with high impact polystyrene, they observed reduction in splitting tensile strength and compressive strength. The high impact polystyrene makes the mortar and increase increases the energy dissipation capacity.

Polystyrene aggregate concrete (PAC) is a light weight concrete that has goof deformation capacity. However, its application is practically limited to non-structural uses due to its low strength properties (Tang et al., 2008). Research in PAC has advanced enormously, extending its uses beyond non-structural uses. Research in PAC has mostly focused on improving the mechanical properties of the specimen.

Expanded polystyrene concrete are prone to segregation due to their hydrophobic surface. A premix method, similar to “sand-wrapping” was developed by (Chen et al., 2004) to make expanded polystyrene aggregate concrete.

(Tang et al., 2008) developed a class of structural graded PAC for concrete densities ranging from 1400 to 2100 Kg/m^3 by partially replacing coarse aggregate with polystyrene aggregate. They characterized the strength in addition to the long term shrinking properties of the samples. Their research studied the mechanical properties such as compressive strength, concrete density and modulus of elasticity. The experiment shows a decrease in compressive strength, concrete density and elastic modulus.

2.2.1 Self-Compacting Concrete (SCC)

The durability of concrete structures has been the center of focus for decades. In the late 1980's, professor Okamura of the Tokyo University Japan developed the self-compacting concrete (SCC) (Okamura, 1997; Okamura et al., 2003). The first sample of the SCC was made in 1988 using already available materials. Based on its ability to consolidate its own weight in the absence of external vibration, it was considered a high performance concrete (HPC) (Okamura & Ouchi, 2003; Shi et al., 2015), and was defined based on the following three stages (Okamura and Ouchi, 2003):

- Fresh stage: self-compactability
- Early age stage: preventing initial defects
- After hardening stage: protection against aggressive factors

Figure 2.2 shows a comparison of mixture proportion between self-compacting concrete (SCC) and normal concrete.

To achieve SCC, the major work is in the appropriate design of mix proportion and evaluation of the concrete properties obtained afterwards (Su et al., 2001). Practically, the fresh state of SCC shows the following characteristics: self-compatibility, fluidity and segregation resistance, all of which reduce the risk of honeycombing of concrete (Chai, 1998).

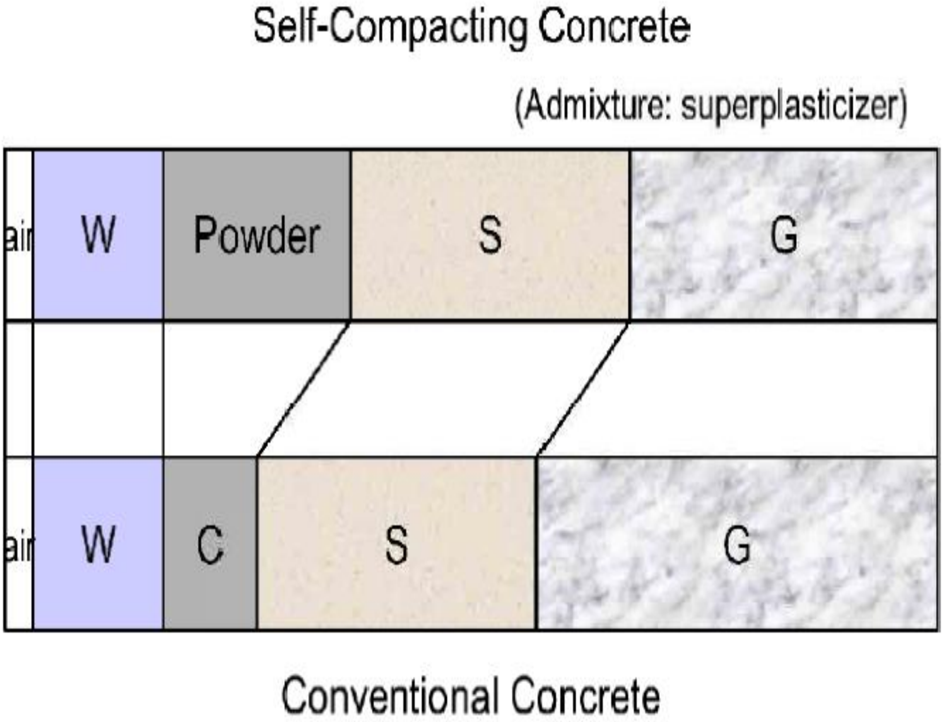

Figure 2.2: Comparison of Mixture Proportioning between SCC and Conventional Concrete (Okamura & Ouchi, 2003)

In spite of the advantages associated with SCC in construction, there has been a limited use of it compared to other construction materials, mostly due to its high self-weight (Lotfy et al., 2014). For that reason, it is easy to think that the incorporation of lightweight aggregate in place of the normal weight aggregate in self-compacting concrete will develop a new high performance concrete (HPC) (Li et al., 2017). This new kind of HPC is known as lightweight self-compacting concrete (LWSCC), thus combining the favorable characteristics of lightweight concrete (LWC) and SCC (Hossain, 2004; Lotfy et al., 2015; Wu et al., 2009).

An example of the lightweight aggregate would be the use of plastic waste (PW) such as polystyrene. The use of such light PW as an aggregate will merge the advantages of LWAC and SCC, thus exhibiting attractive qualities such thermal insulation capacity, reduced dead loads, improved fire resistance, improved durability and high segregation resistance (Wu et al., 2009).

In improving the physical, chemical and mechanical properties of concrete, the factors that are monitored includes: workability, compressive strength, tensile strength, stress-strain reduction and water absorption capacity of concrete.

2.2.2 Micro-silica

High performance concrete requires high tensile strength, improved compressive strength, and reduction in porosity and high durability. It is well documented that incorporating micro-silica in concrete mixtures improves the mechanical properties of concrete (Wang & Meyer, 2012). However, conclusive evidence as to the optimum silica-fume replacement percentage is yet to be presented. Although, improvement as to the utilization of micro-silica is documented.

(K. G. Babu & Babu, 2003) used expanded polystyrene as a lightweight aggregate in concrete and mortars that used micro-silica as supplementary cementitious material. They studied the strength and durability of the concrete, the micro-silica replacement was at 3 %, 5 % and 9 %.

The research by (Chen & Liu, 2004) using expanded polystyrene concrete with steel fibers show~~s~~ that the use of SF with expanded polystyrene concrete improves the bond between the expanded polystyrene and cement paste, thus improving the mechanical properties of the concrete such as the compressive strength. Their result states that SF increases compressive strength by up to 15%. They also noted that at an appropriate level, SF may replace some bonding agents and enhance the strength of expanded polystyrene concrete.

A study by (Mazloom et al., 2004) researched the effect of SF on high performance concrete’s mechanical properties used a constant w/b ratio of 0.35 and various SF percentage (0 %, 6 %, 10 % and 15 %). Their experiments showed improvement in compressive strength and secant modulus after 28 days. However, workability of the concrete decreased during experimentation.

The work of (Bhanja et al., 2005) to identify the isolated contribution of SF to the tensile strength of high performance concrete concluded that the optimum percentage of SF is not constant, but depends on the ratio of water cementitious material mix.

An experimentation was carried out on the effect of SF on tensile strength of concrete by (Wang & Meyer, 2012) with water/binder ratios of (0.26 and 0.42) and SF ratio of (0.1 and 0.3). Their result shows improved compressive and tensile strengths.

2.3 Workability of Fresh Concrete

Water is a primary component of concrete mixtures. Cement paste is made from water and cementitious materials which takes active part in binding constituent materials of concrete together.

Hydration of concrete is the reaction between water and cement to produce cementitious compounds that bind constituent materials of concrete together (Kosmatka et al., 2011). (Gambhir, 1995, 2013) stated that the lubricant between fine and coarse aggregate is water, thus producing a workable concrete.

Workability is one of the physical attributes of concrete, and it covers a wide range of properties such as finish-ability, pumpability, mobility, stability and compactability of the fresh concrete (Anderson et al., 2003). The workability of the fresh concrete is affected by the constituent materials of concrete; water, cement, Coarse and fine aggregates, mineral admixtures and chemical admixtures. The content of aggregate is an important part of concrete; therefore replacing it with PS has effects on concrete workability.

The experiments of (Xu et al., 2012) using expanded polystyrene as an aggregate showed good workability in some type of samples like cylinder, cube and beams . However, some samples showed segregation and collapse due to high percentage of expanded polystyrene which results to low degree of compaction. The test results also show decrease in the density of the specimen when there is increase in thermal insulation properties.

2.3.1 Effects of Polystyrene Beads (PS) on the Workability of Concrete

(K. G. Babu & Babu, 2003) examined the behavior of lightweight expanded polystyrene concrete that contained micro-silica. They concluded that mixtures that have high SF percentages exhibit higher flow values. They added micro-silica and superplasticizer to solve the problem of hydrophobic nature of expanded polystyrene and improve cohesiveness.

Ten samples of polystyrene waste was collected and characterized by nitrogen content in Bucharest by (Sarbu et al., 2009). They studied the possibility of using polystyrene for concrete production, expecting it as a better form of thermal insulation for buildings. The rheological determinations on freshly prepared concrete were used to test the compatibility (an important factor of concrete workability) of hydrophobic matrix. The study shows that PS in cementitious matrix does not have effect on the rheological behavior characteristics for concrete, but enhances thixotropic.

The study of (Tang et al., 2008) which focused on the mechanical and drying properties of PS aggregate concrete, observed the workability of the concrete without admixtures and other factors kept constant. They observed that the Polystyrene aggregate concrete is particularly similar to the corresponding normal weight concrete. They also observed that the Polystyrene aggregate concrete was easily workable and flexible, making it an easy match with tamping rod and easy finish. In general, they observed that the cohesiveness and even distribution of the mortar and concrete matrix is synonymous to normal concrete.

The study on the mechanical characteristics of expanded polystyrene lightweight concrete by (Xu et al., 2012) states that the concrete mixtures show tendency of collapse and degradation due to high expanded polystyrene aggregate content (about 25%), which results to low specimen compaction and contributes to reduction in strength.

2.4 Concrete Compressive Strength

The maximum resistance of axial loading a concrete can withstand shows the compressive strength. It is applied using a compression testing machine. It is usually expressed in N/mm^2, psi, kgf/cm^2. The test is normally performed at age 28 days (Kosmatka et al., 2002).

Compressive strength is the most important mechanical property of concrete. Compressive strength is defined as the maximum load that a certain cross-sectional area of concrete can carry. Some researches shows compressive strength as the primary mechanical characteristics of concrete. Furthermore, for the purpose of quality control and construction industry standards, the compressive strength of the concrete is commonly used (Gambhir, 1995; Neville et al., 1987)

When investigating the addition of new materials in concrete, the main mechanical property of focus is the compressive strength of the concrete. The new incorporated materials in concrete are micro-silica, glass powder, fly ash, blast-furnace slag, rice husk ash, etc. (Vijayakumar et al., 2013).

2.4.1 Effects of Expanded Polystyrene (PS) on the Compressive Strength of Concrete

The experimental test results of (K. G. Babu & Babu, 2003) which used expanded polystyrene on cementitious material containing micro-silica shows that the rate of strength increases initially but decreases as the age increases. From the test results, conclusion can be made that as the percentage of micro-silica increases the rate of strength gain increases. Their results also state that, with compressive strength of 10-25 MPa and concrete density of 800-1800Kg/m^3 coarse aggregate and fine aggregate can be partially replaced by expanded polystyrene aggregate.

The use of high impact polystyrene in development of mortar by (Wang & Meyer, 2012) shows a decrease in compressive strength when sand is replaced with high impact polystyrene. However, the mortar shows increase in ductility and energy dissipation capacity.

The effect of PS aggregate size on the strength of lightweight concrete was studied by (Daneti Saradhi Babu et al., 2006). The concrete used in their study contained fly ash as an additive cementitious material with densities ranged from 1000 to 1900 kg/m^3. Their test results showed that concrete with unexpanded polystyrene aggregate exhibited 70 % greater compressive strength than the expanded polystyrene aggregate concretes. Their work highlighted that expanded polystyrene aggregate concrete with small aggregate shows high compressive strength, and it is more evident as the density decreases compared to higher density concrete.

A research by (Xu et al., 2015) was conducted to study the properties (durability and mechanical) of lightweight concrete incorporating expanded polystyrene beads at different volume levels (0 %, 5 %, 10 %, 15 %, 20 %, 25 %, 30 %, 35 % and 40 %) and two different w/c ratios of 0.45 and 0.55. From the test results, it was concluded that compressive strength decreases as the expanded polystyrene beads volume fraction increases.

(Ranjbar et al., 2015) analyzed the durability and strength of polystyrene aggregate on self-compacting concrete. The mixes were performed at different w/b ratios and polystyrene content of 10 %, 15 %, 22.5 % and 30 % by volume. To test for durability, they investigated the water absorption, air permeability, electrical resistance and chloride penetration profile of the concrete specimen. Their results show higher levels of compressive strength for the polystyrene mixes cured in salt wetting. In their study, after age 90 days, low corrosion was observed for samples with density above 2,000 Kg/m^3.

The effects of expanded polystyrene particles on thermal conductivity, fire resistance and compressive strength of foamed concrete were analyzed by (Sayadi et al., 2016). They used expanded polystyrene volume fraction between 0 and 82.22 %, w/c ratio of 0.33, and concrete used of density ranged from 1200 to 1500 kg/m^3. Their results showed a decreases in compressive strength of the concrete. Further analysis illustrated that as the volume of expanded polystyrene increases the compressive strength reduces.

The study of (Tang et al., 2008) stated that most of their polystyrene aggregate concrete samples realized their corresponding 28 day strength in day 7. However, they observed that the presence of polystyrene decreased the specific thermal capacity of the concrete. This results to heat loss of the concrete to ambient medium during hydration.

According to the results of (Xu et al., 2012), increase in volume of expanded polystyrene and w/b ratio parameter decreases the compressive strength of concrete, moreover, as the sand ratio increases the compressive strength of concrete also increases.

2.5 Young’s Modulus

Another mechanical property of great importance is Young’s modulus, which a measurement of the concrete’s ability to deform elastically. It is represented by the stress-stain slope relation curve, which is about 40% of the compressive strength. Higher elasticity modulus of a concrete show the concrete resistance to deformity (Tia et al., 2005).

Concrete constituent materials influence Young’s modulus of concrete. Therefore, the materials used to substitute aggregates can affect the concrete’s Young’s modulus. The relationship between Young’s modulus and the strength of concrete illustrates that the parameters which affect the concrete also affect its Young’s modulus (Neville and Brooks, 1987).

2.5.1 Effects of Polystyrene Beads (PS) on Concrete Young’s Modulus

The experimental result of (K. G. Babu & Babu, 2003) on expanded polystyrene aggregate concrete containing fly ash states that for every 10 % increase in expanded polystyrene, the secant modulus decreases by 40 %. Concluding that, the modulus of elasticity of expanded polystyrene concrete decreases as the percentage of expanded polystyrene increases. Also similar conclusions on modulus of elasticity were drawn by (Xu et al., 2015).

The study of (Tang et al., 2008) using polystyrene aggregate concrete found the modulus of elasticity to be between 27 and 70 % of the controlled concrete. Due to the negligible elastic modulus of polystyrene aggregate the incorporation between the aggregate and the mix increases, which makes the elastic incorporation higher. Thus reducing the elastic modulus markedly.

(Tasdemir et al., 2017) performed an experimental program on lightweight concrete containing lightweight aggregate including expanded polystyrene beads as an aggregate. They tested the properties of the concrete which includes the mechanical and physical properties, including modulus of elasticity. Their test results showed reduction in Young’s modulus and compressive strength of the concrete as the concrete weight decreases. They noticed more reduction in strength for concrete containing polystyrene beads. The test results also show a strong relationship between Young’s modulus and the unit weight of the concrete.

2.6 Concrete Splitting Tensile Strength

Concrete tensile strength is considered as a prime mechanical characteristic of concrete. Tensile strength is the maximum tensile load to cross-sectional area that concrete can bare before fracture. Because of the brittleness of concrete, it is weak under tension than compression. Cracks develop when concrete is subjected to tensile stresses. Splitting tensile test is the most utilized test technique for investigating the concrete tensile capacity. Splitting tensile strength is an indirect test, which is in general shows higher values than the direct tensile strength of concrete.

ASTM C496/C496M – 11 describe splitting tensile strength test as a compressive load applied along the height of a concrete cylindrical test specimen, placed horizontally, at a certain loading rate until fracture by splitting takes place. The loading produces tensile stresses on the plane that contains the applied force, and high compressive stresses in the region around the applied force.

Splitting tensile strength is used to determine the direct tensile strength of concrete. Thus, factors that affects the concrete strength could also affect the splitting tensile strength. The study of mechanical and drying shrinkage properties of structural–graded polystyrene aggregate concrete by (Tang et al., 2008) presented the relationship between compressive strength and split tensile strength. Figure 2.3 shows the variation of compressive strength and tensile strength. It shows that the splitting tensile strength of polystyrene aggregate concrete increases in a decreasing rate as the compressive strength increase. The splitting tensile strength of polystyrene aggregate concrete ranged from 7.4 % to 9.2 % of the corresponding compressive strength compared to 7.3 % observed for other concrete.

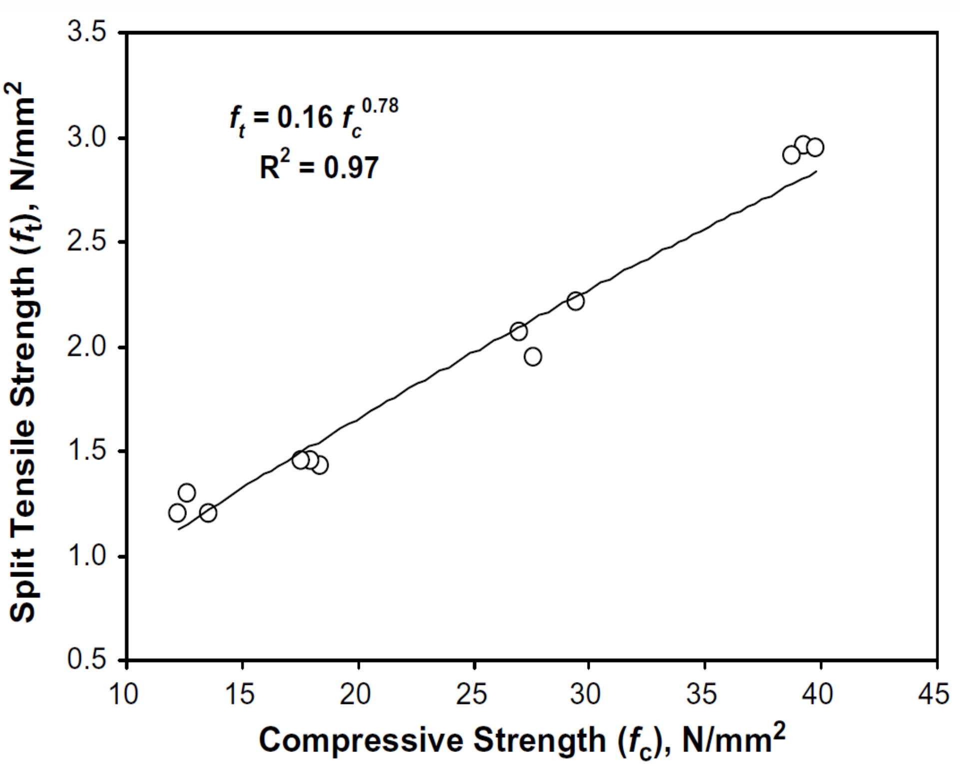

Figure 2.3: Relationship between Splitting Tensile Strength and Compressive Strength (Tang et al., 2008)

The factors that affect the tensile strength of concrete are as follows:

- Component materials: The component materials of mix concrete (cement, water and aggregates) control's the strength of sample in both quantity and quality.
- Dimension (length and diameter) of sample: The cylindrical length does not necessarily affect the test result of a given diameter, however, it can possibly reduce variability of the long test specimen. However, the splitting test result is affected by the specimen diameter (Lamond et al., 2006)
- Loading rate: to achieve higher results in splitting tensile strength test, loading must be done rapidly (Shu Zhang et al., 2016)
- Bearing plywood strips: in order to distribute the applying load, two bearing plywood strips of 3.0 mm and width of 25 mm should be used in accordance with ASTM C496/C496M – 11 (Lamond & Pielert, 2006).

2.6.1 Effect of Polystyrene Beads on the Concrete Tensile Strength

The use of polystyrene in mortar was explored by (Wang & Meyer, 2012), they replaced sand with high impact polystyrene. Their test results showed a marginal decrease in splitting tensile strength of the mortar, increase in energy dissipation capacity and ductility of the mortar.

The result of (K. G. Babu & Babu, 2003) experimenting the behavior of the combination of SF and expanded polystyrene, it shows that the splitting failure mode of concrete samples did not show the typical brittle failure observed in concrete as in compressive strength. Their samples show a failure process that was gradual and the samples did not break into two.

(Serbanoiu et al., 2016) analyzed the advantages of using waste to obtain cement concrete, they used micro-silica and flash ash as a partial replacement with the cement in the concrete. To decrease the density of the concrete, they used polystyrene granules. They determined and discussed the splitting tensile strength of the specimen and other mechanical properties. The properties tested were compressive strength, flexural strength and splitting tensile strength of concrete. The compressive strength was improved with high cement dosage and polystyrene granules. Polystyrene granules decreased the mechanical some mechanical properties. However, impressive mechanical properties were also observed at 10 % and 15 % polystyrene granules content.

The splitting tensile strength of concrete that contained fly ash as an additive cementitious material with densities of 1000-1900 kg/m^3 was examined by (Daneti Saradhi Babu et al., 2006). Their result shows that the splitting tensile strength of concretes incorporating expanded polystyrene aggregates increases with decrease in size of the expanded polystyrene aggregate. Inferring that the size of the polystyrene aggregate affects the tensile strength of the concrete. In contradiction to the test results obtained by (Daneti Saradhi Babu et al., 2006), (Xu et al., 2015) in their research concluded that splitting tensile strength decreases as polystyrene beads volume fraction increases.

2.7 Stress-Strain (σ-ε) Relationship of Concrete

The σ-ε curve shows the relationship between stress and strain of concrete when continuous loading is applied under the control of load or deformation. In compressive σ-ε curve the significant factors are identified in the localization of failure (Komlos, 1969).According to (Komlos, 1969), the factors that affects σ-ε relationship are listed as follows:

- Aggregate/cement ratio
- w/c ratio
- Grading of Aggregate
- Curing conditions
- Loading rate
- Length of test specimen

(Carreira et al., 1985) proposed a general form of serpentine curve to present the complete σ-ε relationship in compression of plain concrete. The concluded that uniaxial σ-ε diagram was affected by some conditions which are:

1. Testing condition

   Shape and size of the sample

   Stiffness of the testing machine

   The type of loading (cycling, preloading etc.)

Strain rate

2. Concrete characteristics

   Cement content

   w/c ratio

   Concrete density

   Aggregates content

3. Specimen age and the curing conditions

Several researches have reported that the properties of the transition zone (ITZ) around aggregate particles are responsible for the properties of concrete such as the failure behavior of concrete when subjected to stresses (Akçaoğlu et al., 2004; Xiao et al., 2013).

The stress-stain results from the study of (D Saradhi Babu et al., 2005) showed that as the strength level increases, the concrete fails at a lower strain level. Also, as the volume of expanded polystyrene decreases, the steepness of the stress-stain curve increases. It was also observed that the failure of the concrete was gradual depending on the level of expanded polystyrene. If the expanded polystyrene aggregate percentage is higher, the failure was more ductile compared to lower percentage of expanded polystyrene.

(Xu et al., 2012) studied the σ-ε behavior of concrete specimens under compressive loading. They used expanded polystyrene as concrete aggregate. They observed that the σ-ε curves are similar to that of normal weight concrete, moreover, as the compressive strength increases the elastic portion of the σ-ε curve increases and the slope increases.

In a study by (Xiao et al., 2013), they concluded that in concretes containing recycled aggregates, the overall σ-ε relationship plays a significant role in the mechanical properties between ITZs and the mortar matrices.

2.8 Concrete Absorption Capacity

According to (ASTM C642 − 13), water absorption capacity is the mass increase in percentage of the oven dry concrete specimen after placing it under water for a certain period of time. It is an important identification of high quality concrete. The water absorption concrete is important to predict some important concrete characteristics such as strength, permeability and sulfate attack resistance (SP Zhang et al., 2014).

The concrete absorption capacity is relevant particularly to test the durability of concrete; sulfate attack, freezing and thawing damage, reinforcement corrosion, alkali-aggregate reaction and ingress of chlorides (Parrott, 1992).

Factors affecting water absorption capacity of concrete include environmental conditions, concrete constituent materials and mixture proportioning's. Moreover, volume of aggregates, w/c ratio and relative humidity affect concrete absorption capacity (Castro et al., 2011).

2.8.1 Effects of Polystyrene (PS) on Concrete Absorption Capacity

The study of PS aggregate size on strength and moisture migration by (Daneti Saradhi Babu et al., 2006) observed that water absorption of expanded polystyrene concrete was higher for concrete with higher amount of expanded polystyrene. Their test results showed that absorption of expanded polystyrene concrete increased as the size and volume of expanded polystyrene aggregate increases. Expanded polystyrene aggregate concrete with higher density (1800 kg/m^3) showed lower absorption than normal weight concrete, and lower density concrete (1000 kg/m^3) revealed greater absorption than normal weight concrete.

(Amianti and Botaro, 2008) conducted an experiment by impregnating concrete with recycled expanded polystyrene (PS). Their test results of impregnation showed that the water absorption demonstrated a more positive result for samples with 10 % expanded polystyrene than samples with 5 % expanded polystyrene. (Kan et al., 2009) stated that, to maximize service life and water absorption of concrete, heat treatment is used on expanded polystyrene.

(Tang et al., 2008) stated that the negligible absorption capacity of PS aggregate concrete enhanced the workability of the fresh concrete.

Studies aimed improving the properties of SCC consider using the lightweight aggregate to produce lightweight self-compacting concrete (LWSCC). A few numbers of studies have examined using polystyrene in SCC concrete.

In one study, the effect of expanded polystyrene on fresh SCC concrete was investigated by (Madandoust et al., 2011). The study used expanded polystyrene in different volume fractions as 10 %, 15 %, 22.5 % and 30 %. The test results showed that, samples with densities greater than 1800 kg/m^3 (up to 22.5%) expanded polystyrene satisfies the SCC criteria.

Chapter 3

RESEARCH METHODOLOGY

3.1 Introduction

In compatibility to the goals of this thesis, five different mixes were created by substituting five different percentages (0, 20, 40, 60 % with 1.75 % G and 60 % with 1.5 % G) of Polystyrene (PS) with coarse aggregates and with one water/binder (w/b) ratio of 0.45. The main aim was to investigate the impacts of PS joined with w/b on mechanical behavior and physical properties of concrete. For this reason the following procedures have been performed:

1-Fresh concrete tests

  1.1 Slump Test

  1.2 L-Box Test

  1.3 V- Funnel Test

2-Compressive strength test before and after heat exposure to 100 ℃ and 200 ºC.

3-Splitting tensile strength test before and after heat exposure to 100 ℃ and 200 ºC.

4-Mass of specimens before and after heat exposure to 100 ℃ and 200 ºC.

5-Flexural Strength test.

6-UPV before and after heat exposure to 100 ℃ and 200 ºC.

7-Degradation resistance to heat tests at 100 ℃ and 200 ℃.

This chapter, covers the depiction of the materials utilized in the over recorded tests. Moreover, it clarifies the different standards that utilized in experimentation and test strategies in detail and the strategies of utilizing machines,.

1.2 Materials Properties

The properties of the materials used in this experimental work are explained in the consecutive segments.

3.2.1 Cement Type

CEM II/B-S 32.5 N slag cement made in Boğaz Endüstri ve Madencilik Ltd cement factory in North Cyprus. This kind of cement has a suitable resistance to sulfate attack in concretes and produce by European standards. The properties of the cement used are depicted in Table 3.1.

Table 3.1: Physical and Chemical Properties of the Slag Cement

Oxide			Percenet (%)
Chemical Properties	IR		0.10
	LOI		10.90
	SO_3		2.20
	SiO_2		18.70
	CaO		60.40
	Free CaO		1.00
	MgO		2.00
	Al_2O_3		4.00
	Fe_2O_3		2.56
Property			Result
Physical Properties	Relative Density		3.00
	Fineness (cm^2/g)		400
	90 µm sieve Residual (%)		0.26
	45 µm sieve Residual (%)		5.24
	w/c ratio		0.28
	Initial time of setting (min)		185
	Compressive Strength (MPa)	2 day	15.8
		7 day	29.9
		28 day	41.3

3.2.2 Mixing Water

Potable water available in the materials of construction laboratory was utilized for all concrete mixtures and water curing for the concrete specimens.

3.2.3 Fine Aggregate

Two different sizes of crushed fine aggregate (5 and 3 mm) were used in this study. Sieve analysis carried out for the determination of particle size distribution according to ASTM C136 M-14. Gradation of the fine aggregate is shown in Figure 3.2.

3.2.4 Coarse Aggregate

Crushed coarse aggregate with size of 10 mm was utilized in this research. The coarse aggregate used conformed for the grading and quality to ASTM C33 M-16. Sieve analysis for the coarse aggregate was done according to ASTM C136 M-14. Grading of the coarse aggregate is shown in Figure 3.2.

3.2.5 Relative Density and Water Absorption Capacity of the Aggregates Used

Relative density and water absorption capacity of coarse and fine aggregates are shown in Table 3.2 and 3.3, respectively. The dust content was done according to ASTM C 117-04. The dust content of the coarse and fine aggregate was 4.2% and 16.5%, respectively.

Table 3.2: Absorption Capacity of Fine and Coarse Aggregates

Aggregate type	Absorption (%)
Fine	1.12
Coarse	1.64

Table 3.3: Relative Density of Coarse and Fine Aggregates

Aggregate type	Bulk relative density		Apparent Relative Density
	Dry	SSD	
Fine	2.510	2.570	2.670
Coarse	2.420	2.450	2.510

Moreover sieve analysis for aggregate size was done and shown in Tables 3.4 and 3.5.

Table 3.4: Grading of Coarse Aggregate

Sieve size (mm)	Mass retained (kg)	Percent retained (%)	Cumulative percent retained (%)	Percent passing (%)	ASTM C33-92 (%)
14	0.00	0.00	0.00	100	100
10	28	2.8	2.8	97.8	85-100
5	856	85.6	88.4	11.6	0-25
2.63	106	10.6	99.0	1.0	0.5
1.18	10	1.0	49.09	0.00	-

Table 3.5: Grading of Fine Aggregate

Sieve size (mm)	Mass retained (kg)	Percent retained (%)	Cumulative percent retained (%)	Percent passing (%)	ASTM C33-92 (%)
10	0	0	0	100	100
5	3	1	1	99	95-100
2.63	51	17	18	82	80-100
1.18	102	34	52	48	50-85
0.6	57	19	71	28	25-60
0.3	36	12	83	17	10-30
0.15	30	10	93	7	2-10
0.075	21	7	100	0	-

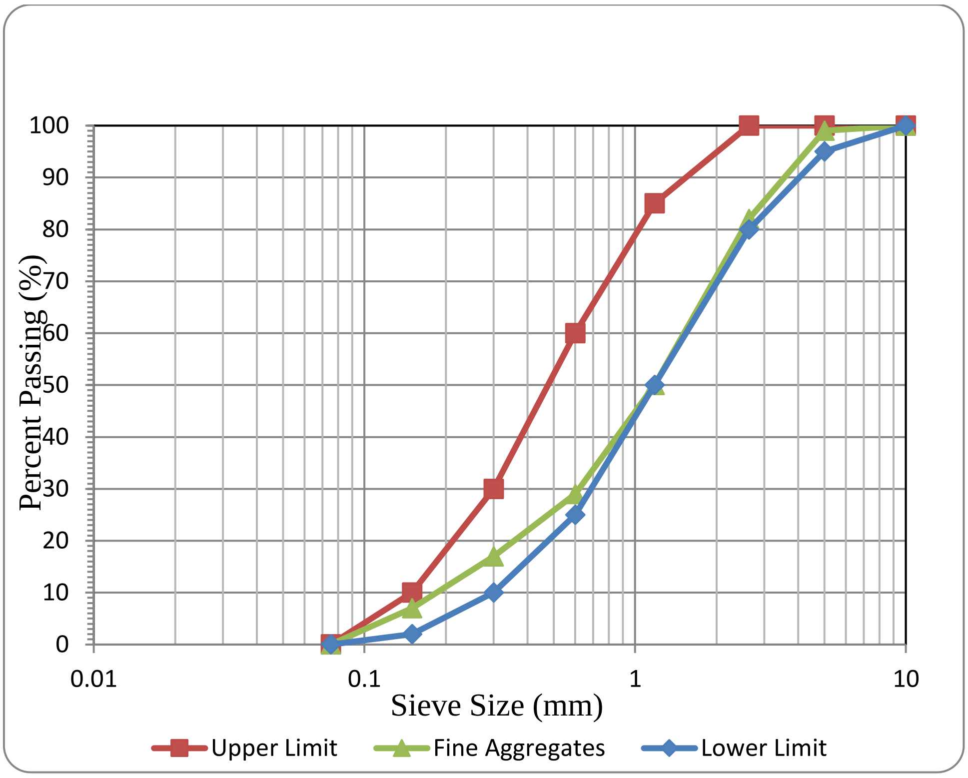

Figure 3.1: Grading of the Fine Aggregate

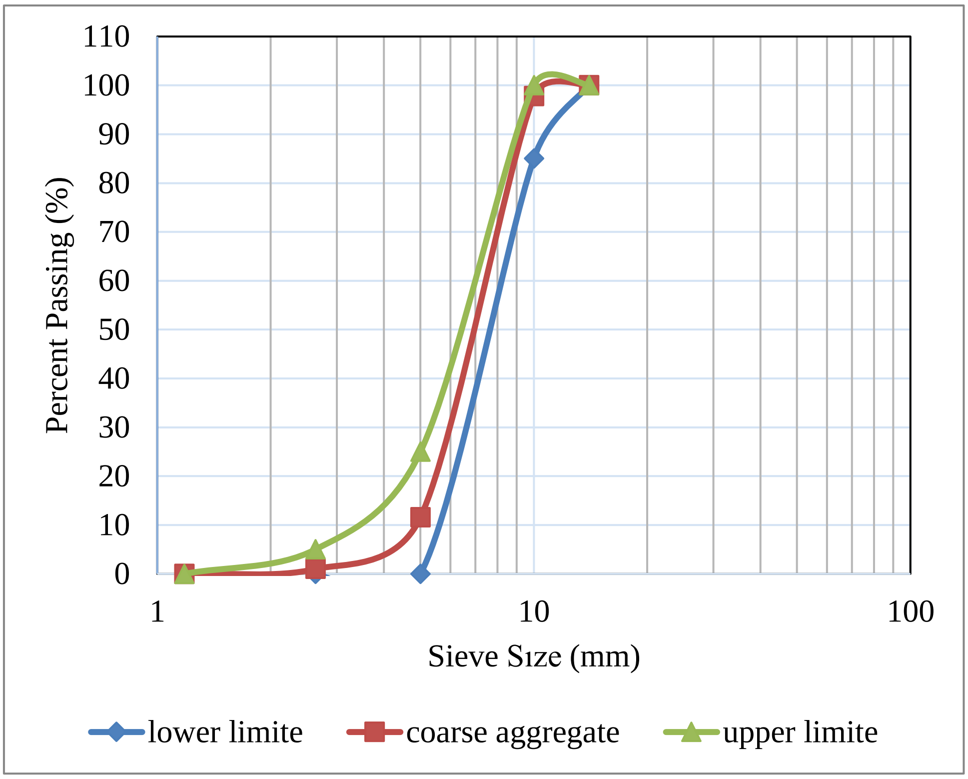

Figure 3.2: Grading of the Coarse Aggregate

3.2.6 Polystyrene (PS)

A manufactured resin which is a polymer of styrene, utilized mainly as lightweight rigid foams and films according to Kaan, A., & Demirboğa, R. (2009). Smooth surface plastic that breaks effortlessly when bowed, utilized in making Styrofoam bundling and protection sheets. Classified as No. 6 Plastic In this study polystyrene used at density equal 23 kg/m³ as a replacement by the volume of natural coarse aggregate.

Figure 3.3: Polystyrene (PS)

3.2.7 Superplasticizer

Master GLENIUM 27 (G) was used as a superplasticizer. It has a high dispersing power, workability retention, excellent reliability and fast strength development. In addition it has a vital part in creating (SCC) and it was used 1.75% of binder (cement + SF) in all percentages (0, 20, 40, 60 % with 1.75% G and 60 % with 1.5 % G) except at 60% since the workability in the mixes increased as plastic particles increased so the GELENIUM 27 content was decreased to 1.5 % to avoid the segregation of plastic aggregate that float to the surface.

3.2.8 Micro-silica

Micro-silica is a byproduct of creating ferrosilicon mixes or silicon metal. One of the most useful employments for micro-silica is in concrete. Concrete containing Micro-silica can be exceptionally durable and can have exceptionally high strength. Micro-silica is available from providers of concrete admixtures. 10 % by the weight of cement was replaced with micro-silica. According to Nikdel (2014),chemical and physical properties of the micro-silica that were utilized in all tests are illustrated in Table 3.6.

Table 3.6: Chemical and Physical Properties of Micro-silica

Oxide	**Percent (%)**
SiO_2	82.2
Al_2O_3	0.50
Fe_2O_3	0.42
CaO	1.55
MgO	0.00
SO_3	3.03
LOI	5.66
Specific surface	29,000 (m^2/kg)
Relative density	2.20

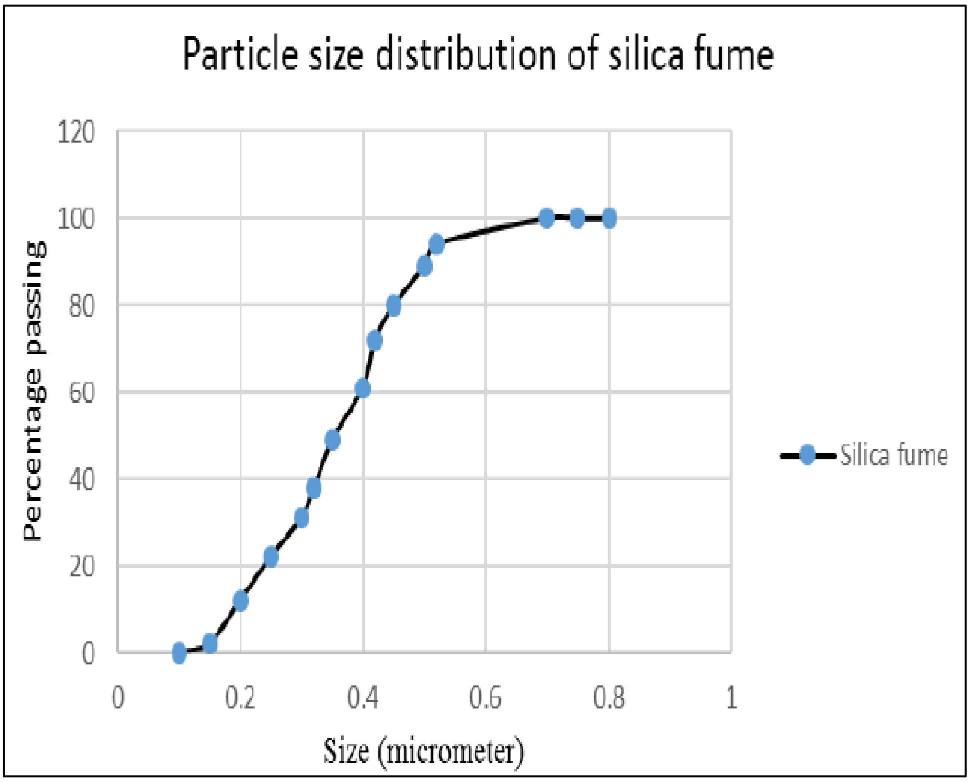

Figure 3.4: Gradation of Micro-silica (Nikdel, 2014)

3.3 Concrete Mixture Proportioning

The easiest description of mixture design proportioning is the calculation of the ratios and quantities of concrete ingredients for the required material properties, workability and characteristic strength to get the most convenient concrete mixture. The mixture proportioning of the PS-SCC concretes are illustrated in Table 3.7

Table 3.7: Quantities and Proportions of the Constituent Materials of Concrete

Type of PS-SCC Concrete Mixture	PS (%)	C (kg/m^3)	PS (kg/m^3)	W (kg/m^3)	FA (kg/m^3)		CA (kg/m^3) (10mm)	SF (10%) (kg/m^3)	(W/b) Ratio	SP
					D max 5mm	D max 3mm				(Kg/m^3)
SCC0PS	0	400	0	198	457.5	457.5	812	40	0.45	7.7
SCC20PS	20	400	1.357	198	457.5	457.5	658.6	40	0.45	7.7
SCC40PS	40	400	2.7453	198	457.5	457.5	501.664	40	0.45	7.7
SCC60PS (1.75G)	60	400	4.118	198	457.5	457.5	346.6	40	0.45	7.7
SCC60PS (1.5G)	60	400	4.118	198	457.5	457.5	346.6	40	0.45	6.6

PS: Polystyrene, C: Cement, CA: Coarse aggregate, FA: Fine aggregate,
SF: Micro-silica, SP: Superplasticizer, W: Water

3.4 Experimental Program

In order to test the impacts of replacing volume of natural coarse aggregate by PS, with five different percentages 0, 20, 40, 60 % with 1.75 % G and 60 % with 1.5 % G with 0.45 w/b ratio was utilized. For this aim, five different concrete mixtures were prepared for the fresh and hardened concrete tests. In this research, all the experiments were compared between every substitution of PS with aggregate and with the control concrete, and the effect of PS on physical and mechanical properties of SCC concrete are explained.

3.4.1 Procedure of PS-SCC Mixing

All concrete mixtures were mixed in a laboratory type concrete mixer with capacity of 32 liters. The dry materials were fed into the concrete mixer in this order: fine and coarse aggregate, micro-silica, cement and finally PS. The concrete ingredients were mixed for almost 45 seconds. Then the superplasticizer and water was added gradually. Therefore, the total mixing time was about 120 seconds.

3.4.2 Fresh PS-SCC Tests

In order to achieve the SCC condition of concrete incorporating five different percentages of PS (0, 20, 40, 60 % with 1.75 % G and 60 % with 1.5 % G) as a partial replacement with coarse aggregate, the workability of the concrete mixtures was assessed by L-Box test, V-Funnel test and slump test.

3.4.2.1 Slump Flow Test

The concrete slump test is utilized to evaluate the horizontal flow of PS-SCC. On removing the slump cone, the fresh concrete flows. The flow diameter is taken as the average of two diameters at right angles of the spreaded concrete circle across the concrete for the padding capacity of the fresh concrete. The range of slump flow test is between 500-700 mm according to Peterson O., Billberg P., and Van B.K (1996).

Figure 3.5: Concrete Slump Test

3.4.2.2 V-Funnel Test

The flowability of the new concrete could be examined by the V-funnel test, where the time of flow is measured. Figure 3.5 shows V-funnel apparatus. The V-funnel is full with 12 liters of concrete and the time taken for the concrete to flow through the device is recorded. In case the concrete segregates, the flow time will increase. Concurring to Manai and Khayat (2007), a V-funnel flow time of less than 6 sec is recommended for a concrete to qualify for an SCC, nevertheless the range of V-funnel flow time can be between 6 -12 sec.

Figure 3.6: V-Funnel Testing Equipment

3.4.2.3 L-Box Test

The passing capability can be found by utilizing the L- box test according to Khayat (2007) as depicted in Fig 3.7. The L-Box device is filled with concrete, then the gate is opened to let the concrete stream into the horizontal segment. The length of the concrete at the end of the horizontal segment is cleared as a rate of that remaining in the vertical segment (H2/H1). This is a sign of passing capacity. The indicated essential is the proportion between the heights of the concrete at each end or blocking proportion to be 0.8

Figure 3.7: L-Box Testing Equipment

Table 3.8: Recommended Limits for Different Fresh SCC Concrete Test Types

Test Type	Limits
Slump flow diameter	500-700 mm
V-Funnel	6-12 Sec
L-Box (H2/H1)	≥ 0.8

3.4.3 Preparation of Test Specimens and Curing Conditions

In this research, four different sizes and shapes of test specimens were used in order to investigate the behavior and properties of the hardened PS-SCC concretes. These are three cylinders of size 100x200 mm, three cubes of size 150×150×150 mm, three beams of size 100x100x500 and three cubes of size 100x100×100 mm were used for all of the concrete mixtures.

Prior casting the concrete in steel molds, the molds were cleaned and then oiled to avoid any possible reaction between steel and concrete and to achieve easier demolding.

After applying fresh concrete tests which are L-Box test, slump test and V-funnel test, the fresh concrete was mixed 45 sec more. After mixing is completed, the steel molds were filled as it can be seen in Figure 3.8

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Figure 3.8: Cylindrical, Cubic and Beams Test Specimens

The concrete test specimens were kept in a curing-room for 24 hours (relative humidity of 99 %). After 24 hours, the concrete specimens were stripped and then were placed in water for curing at a constant temperature of 22 ± 2 °C. The specimens were kept in water curing for 28 days until the day of experimentation. Figure 3.9 shows the concrete test specimens placed in the water curing tank.

Figure 3.9: Water Curing of Concrete Specimens

3.5 Hardened PS-SCC Tests

In order to meet the goals of this investigation, the consecutive tests were conducted to test hardened concrete properties.

3.5.1 Compressive Strength Test of PS-SCC

Fifteen cubes of size 150 mm were used for the compressive strength tests after 28 days in order to compare different properties among the control specimens with 0 % replacement level of Polystyrene (PS) and the other test specimens with different percentages of 20, 40, 60 % with 1.75 % G and 60 % with 1.5 % G of PS as a replacement by volume of coarse aggregate. Figure 3.10 shows the compressive strength of the specimens in the machine.

Figure 3.10: Compression Testing Machine

3.5.2 Splitting Tensile Strength Test of PS-SCC

Fifteen cylinders with 100 × 200 mm were utilized for splitting tensile strength test after 28 days. To decide the effect of replacing aggregate with different percentages of Polystyrene on tensile strength and to compare them with control specimens with 0 % replacement of PS. The test was performed on three specimens for every proportion of PS as it is depicted in Figure 3.11.

Figure 3.11: Splitting Tensile Strength Testing Device

3.5.3 Ultrasonic Pulse Velocity Test (UPV) Test of PS-SCC

An UPV test, was done to anticipate compressive strength of concrete without fragmentation the test specimens.

This experiment, through the concrete specimen can be assesses the time of ultrasonic wave takes to travel between two probes positioned on opposing surfaces of sample. By calculating the travelled time through the concrete specimens, the ultrasonic wave velocity can be evaluated in accordance with BS 1881: Part 201: 2009. The same cubic test specimens for testing compressive strength were used for the UPV test and prior to the former test after 28 days. Figure 3.12 shows the UPV test. The facades of specimens were lubricated, afterward the transmitter and receiver were placed on midpoint of two antagonistic sides of the concrete test specimen. The time travelled in micro seconds can be seen on the screen of the UPV device. Pulse velocity (km/sec) was determined by dividing the length of test specimen over the time travelled.

Figure 3.12: Ultrasonic Pulse Velocity Test (UPV) Device

3.5.4 Flexural Ductility Test of PS-SCC

Fifteen beams with 100 × 100 × 500 mm were included five proportions 0, 20, 40, 60 % with 1.75 % G and 60 % with 1.5 % G of PS as a partial replacement of coarse aggregate, were utilized to amount the changing of flexural strength between the control one with 0% and the others. In organize to draw the flexural ductile strength chart those beams tested in the flexural tensile strength machine, the pressure was ongoing without shock and increased constantly till the first crack, with increasing progressively the rate of load as 0.02 MPa/min till the beams failed as it is depicted in Figure 3.13.

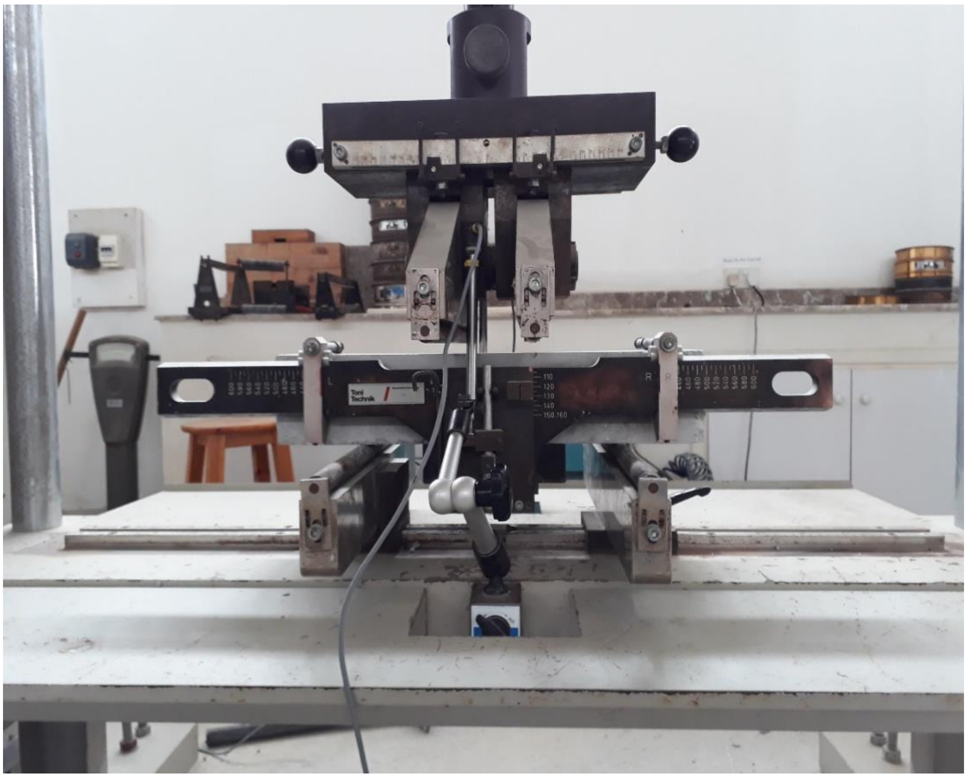


Figure 3. 13: Flexural Load-Deformation Test Setup with Two LVDT's Placed on the Yoke

3.5.5 Heat Degradation Test of PS-SCC

In order to measure the change in UPV, weight, splitting tensile strength and compressive strength under the effect of heat exposure at temperature of 100 ºC and 200 ºC with 10 ℃ increment rate, 90 cube of size 100 mm were used for this experiment.

The specimens were putted in the oven around 4 hours, after that the oven was turned off in order to could down for 15 hours. The weight an UPV of specimens were measured before placed the specimens in the oven. Finally those cube were taken outside of oven around 2 hours according to Albano, C. et al (2009), to measures ultrasound pulse velocity, weight, compressive and flexural strength after that test.

3.5.6 Measurement of Cracks on the Surface of Test Specimens before and After Heat Exposure

Microscope was very important machine to discover cracks on the surface of samples and to measure the width of cracks by millimeters. This experiment was done to study the effect of temperature on PS-SCC specimens before and after heating at 100 and 200 ℃. Figure 3.15 shows the usage of stereo-microscope for specimens.

Figure 3. 14: Investigating Cracks on the Surface of Specimens by Using Stereo-Microscope

Chapter 4

RESULTS AND DISCUSSION

4.1 Introduction

The impact of five different percentages of PS on the mechanical and physical properties for five different types of concrete 0, 20, 40, 60 % with 1.75 % G and 60 % with 1.5 % G were investigated. The specimens adjusted with PS were compared with control specimens for each test. The following tests such as workability, flexural strength, splitting tensile strength, compressive strength, heat resistance, ultrasonic pulse velocity (UPV) and cracks examination with stereo microscope were performed. In order to study specific impacts of PS on the physical and mechanical properties of concrete. For analyzing the test results, results are demonstrated with different graphs and tables for comparison purposes in various aspects and for best understanding.

4.2 The Effects of Different PS Replacement Levels on the Workability of PS-SCC Concrete

The V-Funnel test, L-Box test and slump flow test results of fresh concrete blends for five different percentages of PS 0, 20, 40, 60 % with 1.75 % G and 60 % with 1.5 % G as a partial replacement (by volume) with normal coarse aggregates with 0.45 w/b ratio are illustrated in Table 4.1, 4.2 and 4.3. As it is clear from the Figure 4.1, 4.2 and 4.3, PS has a great impact on the workability of fresh SCC.

Table 4.1 and Figures 4.1, 4.2 and 4.3 show that when the percentage of PS is increased from 20 to 60, SCC satisfied the required workability from 673.5 mm to 697.5 mm.

The ratio value of the vertical to horizontal segment (H2/H1) increased from 0.9 to 1. In other words. For v-funnel test, the v-funnel flow time increase as the percentage of PS in the mix increase, this because the incorporation of plastic material in concrete increase the cohesiveness of the mix, and the resistance against the flow, so the movement of concrete in the v-funnel apparatus slow down, as well as, the plastic beads accumulate together and stuck in the outlet of the apparatus. When the amount of GLENIUM 27 was decreased to 1.5 % with 60 % PS, the workability decreased.

Table 4.1: Fresh Concrete Test Results for PS-SCC

Type of PS-SCC Mixture	Test results of fresh Self-compacting concrete			Self-compacting concrete
	Slump flow test (mm)	V-Funnel test (sec)	L-Box test (H1/H2)	
SCC0PS	650	7.0	0.90	Satisfied
SCC20PS	673.53	7.50	0.92	Satisfied
SCC40PS	688	7.7	0.95	Satisfied
SCC60PS with 1.75 % G	697.5	9.0	1.00	Satisfied
SCC60PS with 1.5 % G	693.5	8.5	0.97	Satisfied

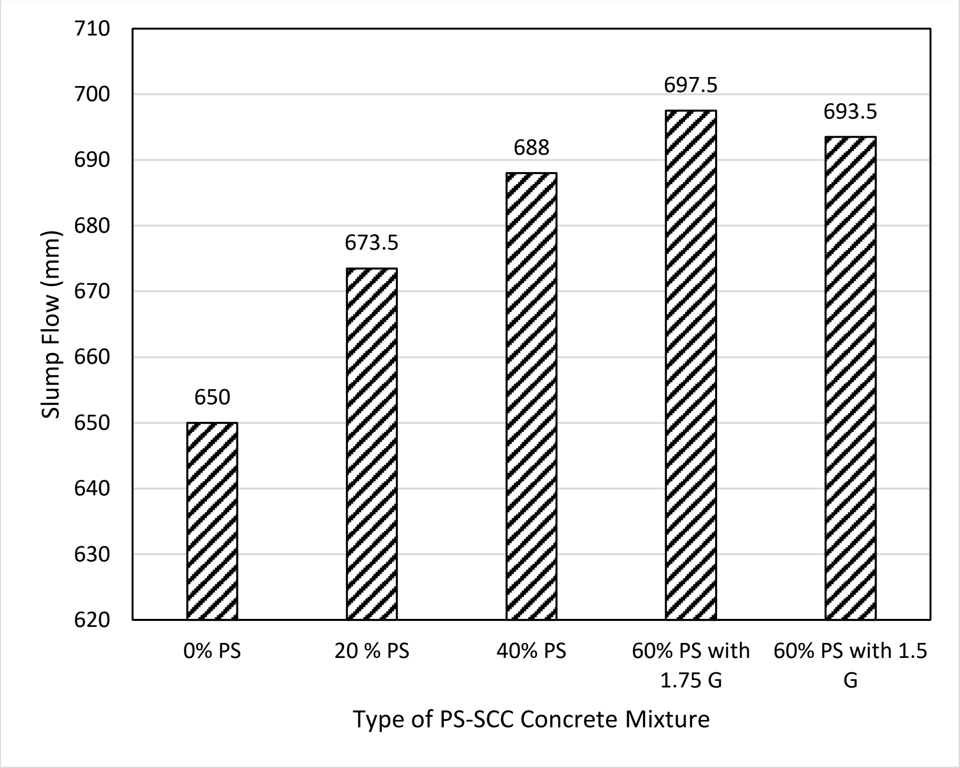


Figure 4.1: Slump Flow Test Results

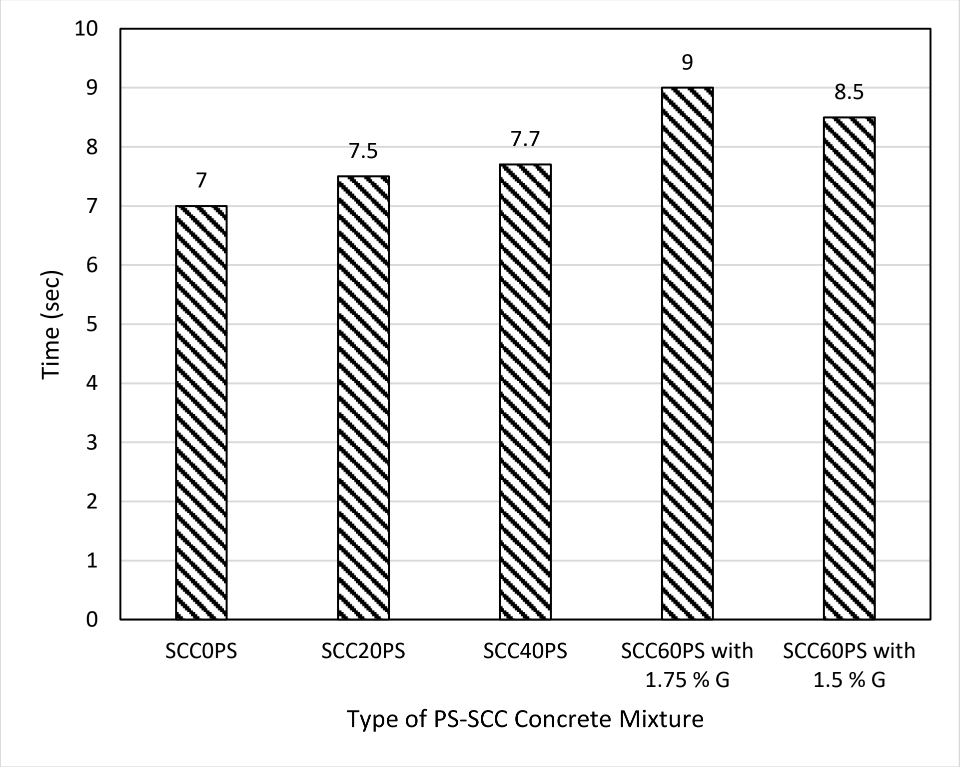


Figure 4.2: V-Funnel Test Results

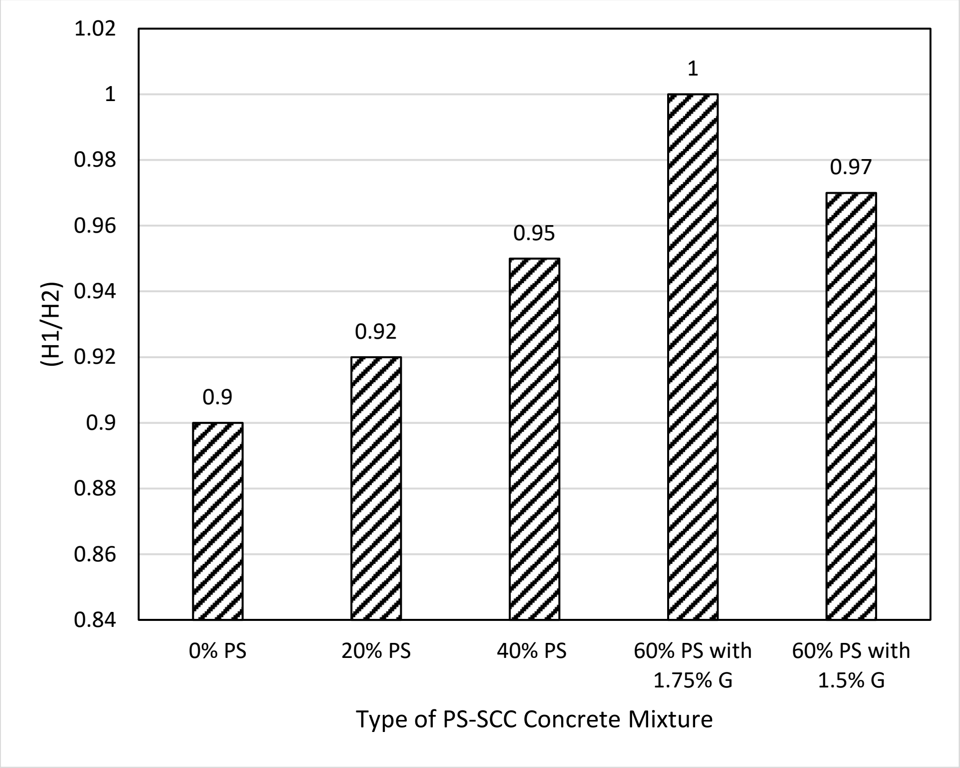


Figure 4.3: L-Box Test Results

4.3 Relationship between Slump Test and V-Funnel Test

Table 4.2 and Figure 4.4 show the correlation between v-funnel and slump flow test .As slump flow test increase v-funnel test increase

Table 4.2: Relationship between V-Funnel and Slump Test for PS-SCC

Concrete type	Regression type	Equation	R^2
PS-SCC	Exponential	$y = 0.3216e^{0.0047x}$	0.82
	Linear	$y = 0.037x - 17.234$	0.7947
	Logarithmic	$y = 24.809\ln(x) - 153.88$	0.7888
	Polynomial	$y = 0.0012x^2 - 1.5304x + 510.09$	0.9192
	Power	$y = 9E\text{-}09x^{3.157}$	0.8145

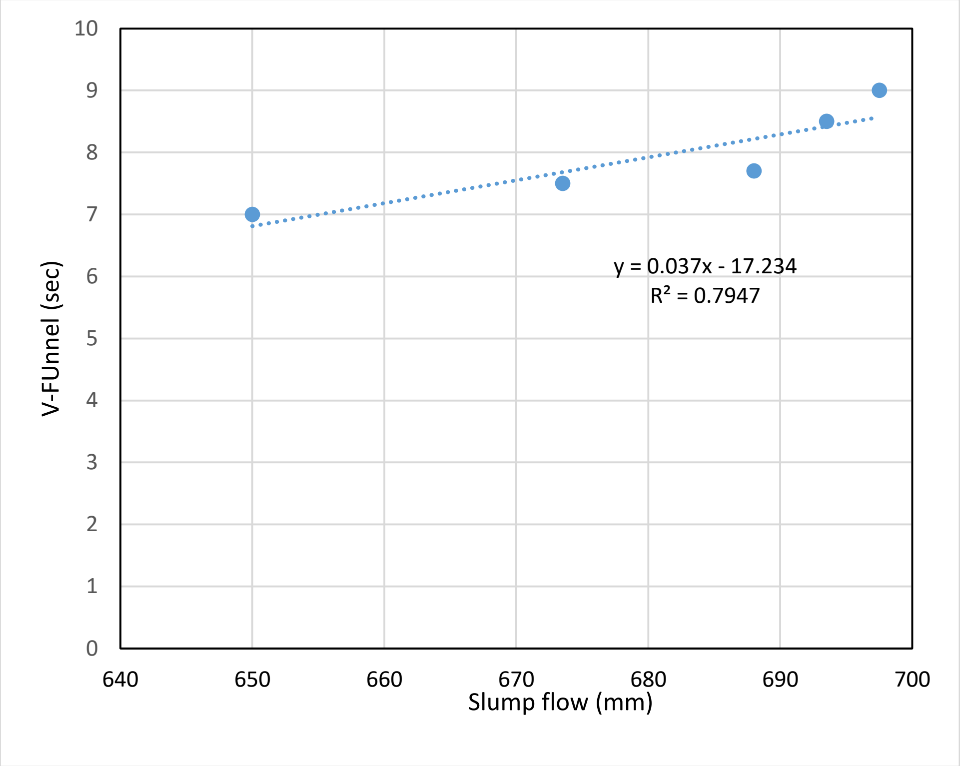


Figure 4.4: Relationship between V-Funnel and Slump Flow Test

4.4 Relationship between Slump Test and L-Box Test

Table 4.3 and Figure 4.5 show the relationship between slump flow and L-Box test of PS-SCC concretes. As it can be seen from Figure 4.5, when the slump increased L-box test also increased.

Table 4.3: Relationship Equation between L-Box and Slump Flow Test for PS-SCC Concrete

Concrete type	**Regression type**	**Equation**	**R^2**
PS-SCC	Exponential	$y = 0.2397e^{0.002x}$	0.873
	Linear	y = 0.0019x - 0.3483	0.863
	Logarithmic	y = 1.2778ln(x) - 7.3865	0.857
	Polynomial	$y = 6E\text{-}05x^2 - 0.0732x + 24.926$	0.9801
	Power	$y = 0.0001x^{1.355}$	0.8672

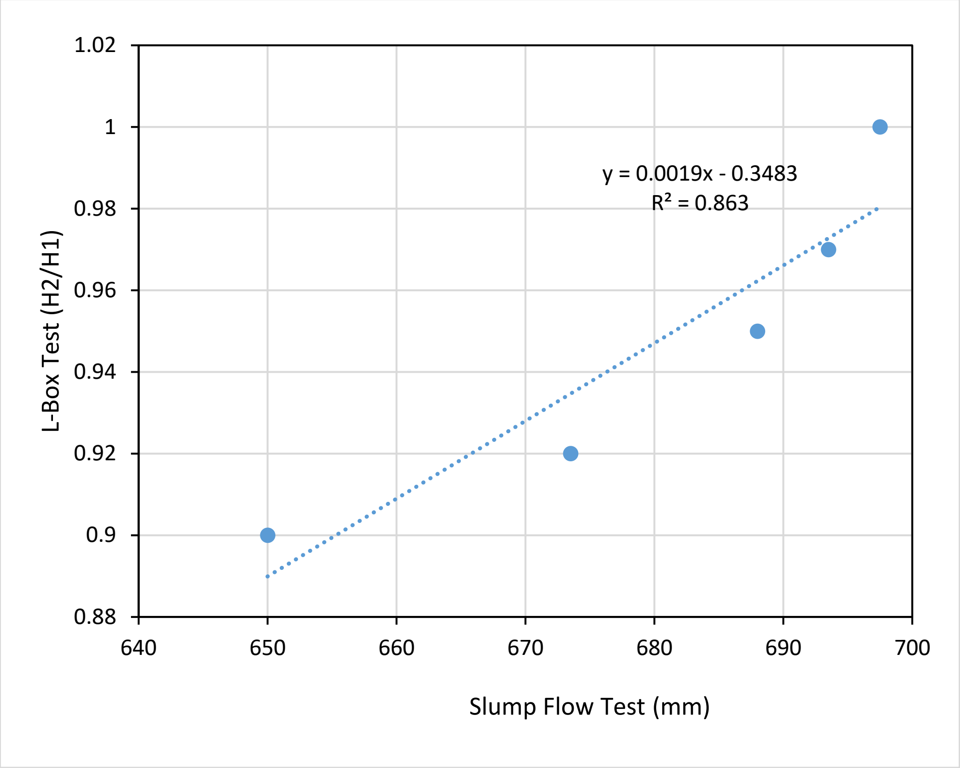


Figure 4.5: Relationship between Slump Test and L-Box Test

4.5 Relationship between L-Box Test and V-Funnel Test

Table 4.4 and Figure 4.6 show the relationship of L-Box test with V-Funnel test of PS-SCC. As it can be seen from Figure 4.6 when the L-box increased V-Funnel test also increased.

Table 4.4: Relationship between L-Box Test and V-Funnel Test for PS-SCC Concrete

Concrete type	Regression type	Equation	R^2
PS-SCC	Exponential	$y = 0.7506e^{2.4839x}$	0.9606
	Linear	y = 19.809x - 10.839	0.9581
	Logarithmic	y = 18.769ln(x) + 8.9554	0.9558
	Polynomial	$y = 46.11x^2 - 67.752x + 30.672$	0.9627
	Power	$y = 8.9823x^{2.3547}$	0.9593

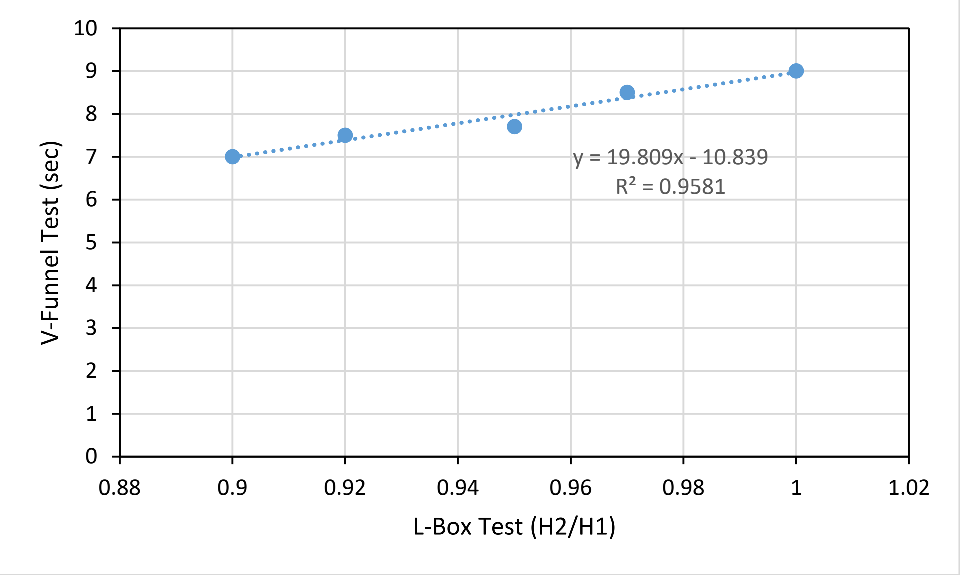


Figure 4.6: Relationship between L-Box Test and V-Funnel Test

4.6 The Effects of Different PS Proportions Replacement Levels on the Compressive Strength of PS-SCC

After 28 days of curing, fifteen specimens 150 mm were utilized to test the compressive strength with the replacement Polystyrene PW for five different percentages 0, 20, 40, 60 with 1.5 % G and 60 with 1.75 % G. In addition to the test results in Table 4.5 and Figure 4.7, Figure 4.8 shows the loss of compressive strength with respect to that of the control specimen.

In this study, the maximum and minimum compressive strength test results at age of 28 days were 59.63 and 29.27 MPa, respectively (see Table 4.5). Polystyrene PW had a great impact on the compressive strength. The volume of PS had the most critical impact on the volume of PS was at 28 days. Since PS aggregates have nearly zero strength, according to Babu, Daneti Saradhi and K. Ganesh Babu (2006), the strength of PS concrete is generally affected by the PS aggregate dosage. Based on Table 4.5, the higher percentage replacement level of PS leads to an increase of 51 % in the rate of the compressive strength reduction from 49.5 to 29.27 MPa. Also as the percentage of Polystyrene increased the bulk density of concrete mix decreased.

In addition, the superplasticizer GLENIUM 27 has an effective influence on compressive strength, when the percentage of GLENIUM 27 decreased up to 1.5 % at 60 % replacement level, the loss of compressive strength compared to the control results increased to 68.7 %.

Table 4.5: Compressive Strength Test Results of PS-SCC

Type of PS-SCC Concrete Mixture	Load (KN)	Compressive Strength (MPa)	Loss of Density (kg/m^3)	Loss of Compressive Strength (%)
SCC0PS	1350	59.63	2343	-
SCC20PS	1113.67	49.5	2166	-17
SCC40PS	1038.33	46.133	2079	-22.6
SCC60PS with 1.5 % G	422.33	18.67	2048	-68.7
SCC60PS with 1.75 % G	658.33	29.27	2154	-51

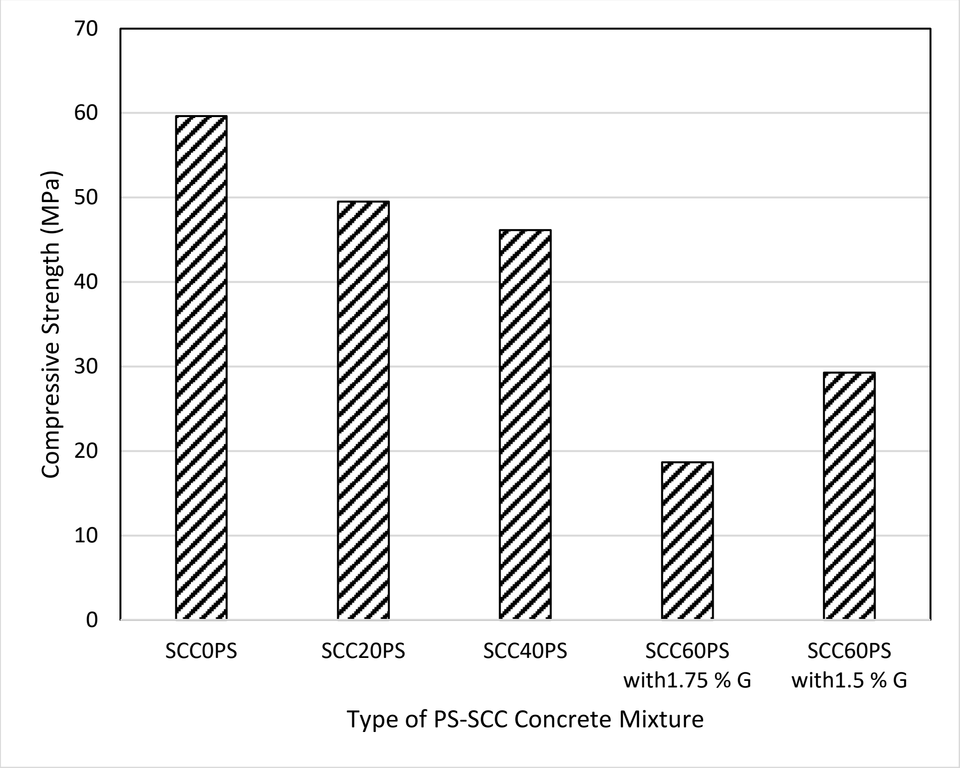


Figure 4.7: Compressive Strength Test Results of PS-SCC Concrete

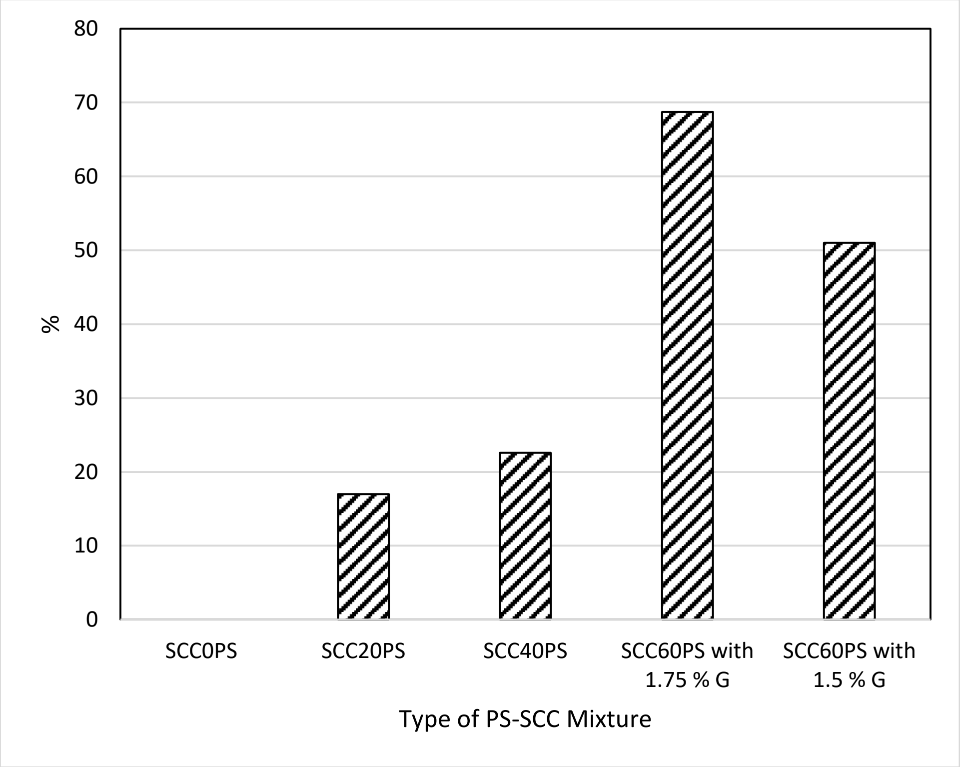


Figure 4.8: Loss of Compressive Strength Compared to the Control PS-SCC Concrete Test Results

4.7 The Effects of Different PS Proportions Replacement Levels on the Splitting Tensile Strength of PS-SCC

After 28 days of curing, fifteen cylindrical specimen 100×200 mm were used to test the splitting tensile strength with the replacement Polystyrene (PS) for five different percentages 0, 20, 40, 60 % with 1.5 % G and 60 % with 1.75 % G. The test results in Table 4.6 and Figures 4.9, 4.10 show the loss of splitting tensile strength compared to the control test specimens.

Similar behavior to the splitting tensile strength, the compressive strength of PS aggregate concrete also reduced with reduce in PS aggregate size. From the Table 4.6 and Figures 4.9 and 4.10, the highest value for splitting tensile strength (3.78 MPa) accomplished when 40 % of aggregate replaced by Polystyrene. When the percentage of PS increased from 20 to 40 %, splitting strength increased from 3.65 up to 3.78 MPa, respectively. Moreover, when the percentage of PS increased by more than 40 % to reach 60 %, the splitting tensile strength reduced from 3.78 to 2.63 MPa, respectively. This means that at 40 % is the optimum value. The interfacial transition zone in concrete ITZ weakness between replaced aggregate and matrix (cement paste) is dominant in splitting tensile strength value. Splitting tensile strength is really controlled by ITZ rather than the aggregate properties.

GLENIUM 27 has an influence on splitting tensile strength, because when the proportion of GLENIUM 27 decreased to 1.5 %, splitting strength returned and increased to 3.12 MPa. At the end, it can be said that all values were reduced compared to the control SCC specimens.

Table 4.6: Splitting Tensile Strength Test Results of PS-SCC

Type of PS-SCC Mixture	Load (KN)	Splitting Tensile Strength (MPa)	Loss in Splitting Tensile Strength (%)
SCC0PS	156.9	4.995	-
SCC20PS	114.8	3.6545	-26.83
SCC40PS	118.73	3.78	-24.32
SCC60PS with 1.5 % G	98.1	3.12	-37.53
SCC60PS with 1.75 % G	82.6	2.63	-47.34

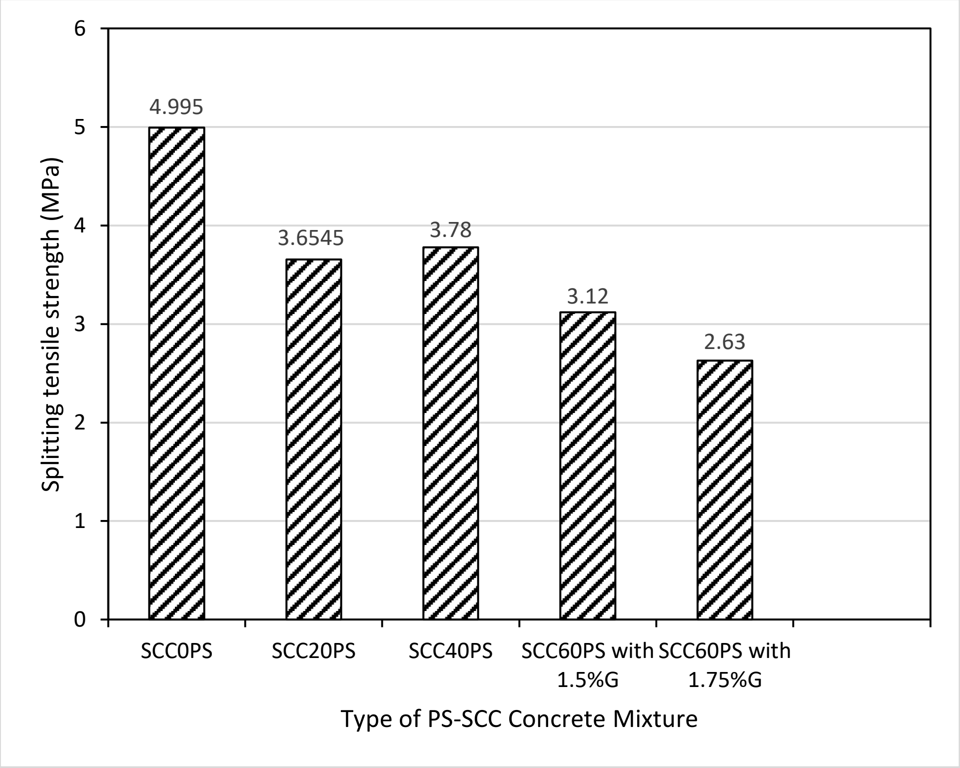


Figure 4.9: Splitting Tensile Strength Test Results of PS-SCC Concrete

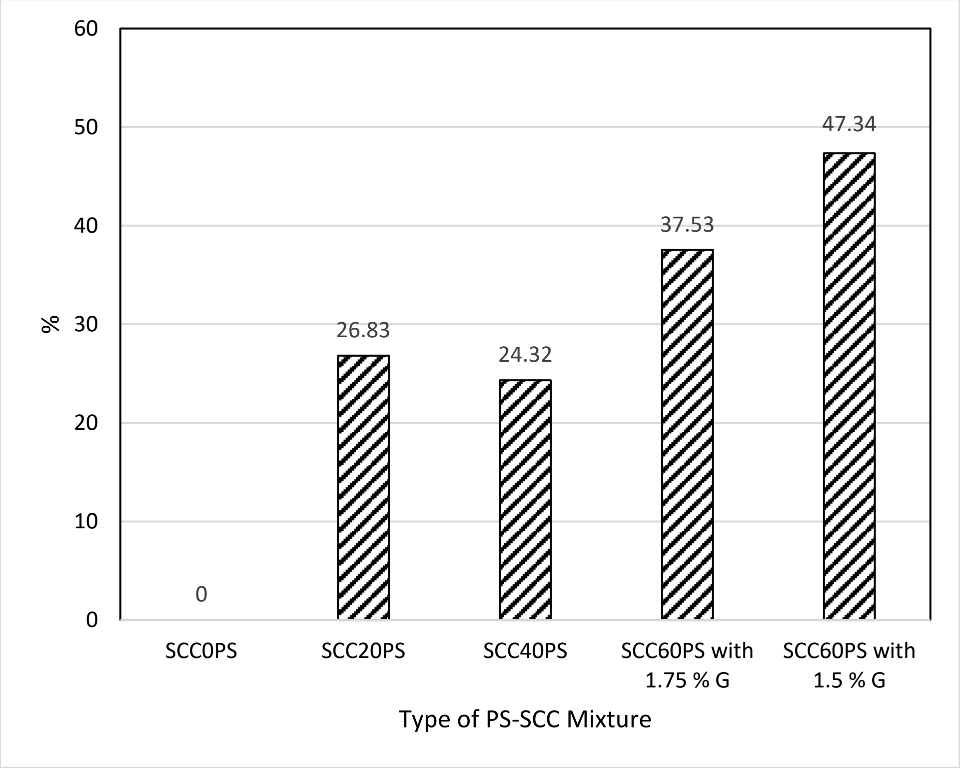


Figure 4.10: Loss of Splitting Tensile Strength Compared to the Control PS-SCC Test Results

4.8 Degradation Test Against Heat at 100 and 200 ℃

The aim of this experiment is to quantify the impact of degradation of PS-SCC against heat exposure at 100 ℃ and 200 ℃ by loss in weight, splitting tensile strength, ultrasonic pulse velocity and cracks development after heat exposure test and compressive strength of PS-SCC of cubes of size 100 mm. The tested PS-SCC include five different percentages 0, 20, 40, 60 % with 1.75 % of G, 60 % with 1.5 % of G of PS PW as a replacement by volume of normal coarse aggregate in two diverse temperatures as 100 ℃ and 200 ℃ separately.

4.8.1 The Impact of High Temperature on the Weight Loss of PS-SCC

According to the specimens that have been tested in oven with different temperatures 100 ℃ and 200 ℃, it appears that different temperatures have an effect on weight loss of cubes 100 mm, with different proportions 0, 20, 40, 60 % with 1.75 % of G, 60 %

with 1.5 % of G of PS as a substitution by the volume of normal coarse aggregate when compared to the control specimens.

Table 4.7 and Figure 4.11 show the weight loss of the PS-SCC concrete test specimens prior and after exposure to heat at 100 and 200 ℃. It can be clear from Figure 4.11 that whenever the temperature increases the weight of specimens reduces. This can be attributed to the fact that PS is a lightweight material, the effect of raised temperatures reduces the weight loss of the concrete specimens. The change in the mechanical properties of concrete when exposed to high temperatures is attributed to the resulting weight loss in concrete. Furthermore, during exposure to elevated temperature the water evaporates with an increase of temperature, this evaporation process leads to weight loss. These losses were approximately 0.6 % and 8 % after subjecting to 100 and 200 ℃, respectively. It is worth noted that here, at different percentages of GLENIUM 27 has an influence on the weight loss of specimens, when the percentages of GLENIUM 27 decreased to 1.5 % at 60 % PS the weight of specimens increased about 5 %.

Table 4.7: Weight before and after Exposure to 100 and 200 ℃

Type of PS-SCC Mixture	Mass of specimen (kg)		
	Before heat exposure	After heat exposure at 100℃	After heat exposure at 200 ℃
SCC0PS	2.343	2.3275	2.1600
SCC20PS	2.166	2.1510	2.0586
SCC40PS	2.079	2.0645	1.8445
SCC60PS with 1.75 % of G	2.048	2.0330	1.7283
SCC60PS with 1.5 % of G	2.154	2.1406	1.8090

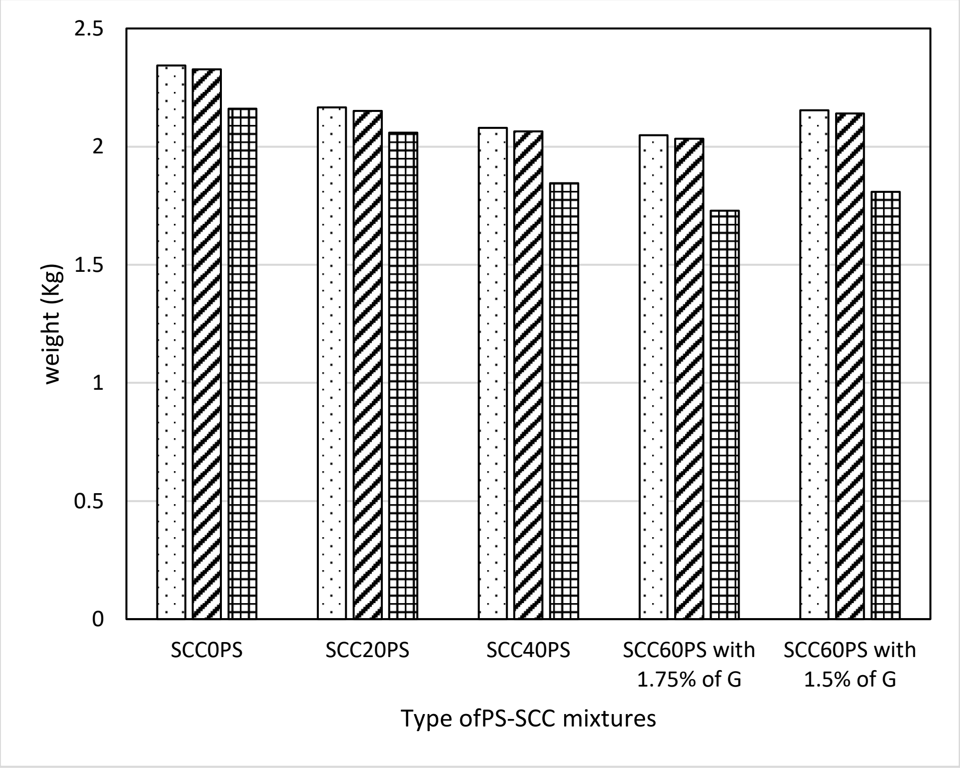


Figure 4.11: Weight Loss of PS-SCC Concrete Specimens before and after Heat Exposure at Temperature of 100 and 200 ℃

4.8.2 The Effect of High Temperature on the Ultrasonic Pulse Velocity (UPV) of PS-SCC

Difference of temperature has an effect on ultrasonic pulse velocity (UPV) with different percentages (0, 20, 40, 60 % with 1.75 % of G and 60 % with 1.5 % of G) of PS as a replacement with coarse aggregate. This effect can be seen through the change that has occurred in the values. Table 4.8 and Figure 4.12 show different values of UPV after 100 and 200 °C compared to specimens before exposure to heat.

As it obvious in Table 4.8 and Figure 4.12, when the replacement percentages of PS with coarse aggregates increased, the UPV reduced about 7 % between the maximum and minimum value, also after heating at 100 °C the velocity reduced approximately 11 %. Again, this occurs after heating at 200 °C, the UPV reduced about 10 % when the percentages of PS was increased. It is clear from the Table 4.8, when the temperature increased UPV decreased, for example, the UPV value at 20 % PS replacement level is 4.525 km/s before heating and decreased 3.5 and 14 % after heating at 100 and 200 °C, respectively. During the exposure of concrete specimens to high temperature at 200 °C, evaporation of moisture took place leaving behind voids in the concrete mass (Hassan, 2007). On the other hand, exposure of concrete specimens at 200 °C caused fine cracks due to the change in volume, both of these increased the transit time for the pulse and the lower velocity.

When the proportion of GLENIUM 27 reduced at 60 % from 1.75 % up to 1.5 % G, the UPV value increased before heating about 3.3 %, at the same time the values of UPV at 60 % with 1.5 % G decreased 0.8 and 20 % after heating at 100 and 200 °C, respectively.

Table 4.8: UPV Test Results of PS-SCC Concrete before and after Heat Exposure at 100 and 200 ℃

Type of PS-SCC Mixture	UPV (km/s)		
	Before heat exposure	After heat exposure at 100 ℃	After heat exposure at 200 ℃
SCC0PS	4.82	4.5	4.00
SCC20PS	4.525	4.366	3.891
SCC40PS	4.504	4.048	3.745
SCC60PS with 1.75 % of G	4.477	4.011	3.597
SCC60PS with 1.5 % of G	4.629	4.594	3.683

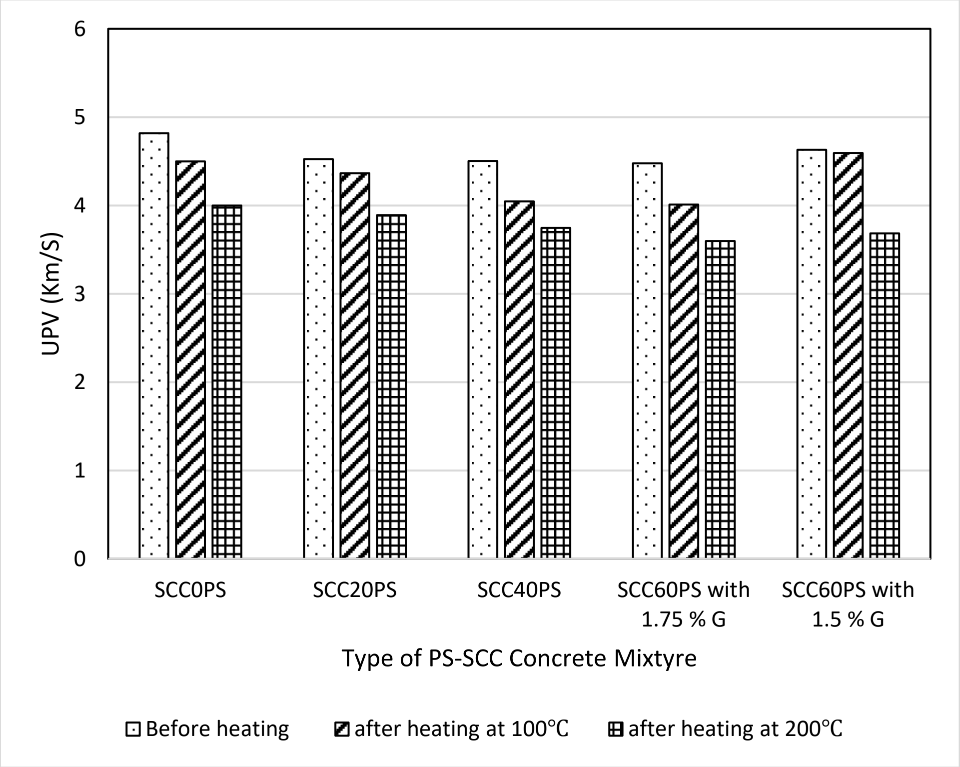


Figure 4.12: UPV Test Results of PS-SCC Concrete before and after Exposure to Heat at 100 and 200 ℃

4.8.3 The Effect of High Temperature on the Compressive Strength of PS-SCC

Table 4.9 and Figure 4.13 show the compressive strength of PS-SCC test specimens (cube of size 100 mm) containing PS as a replacement by volume with coarse aggregates at ratios of 0, 20, 40, 60 % with 1.75 % of G, 60 % with 1.5 % of G exposed to a laboratory condition before heating and at high temperatures 100 and 200 ℃ following 28 days of standard curing.

For the control specimens, when exposure temperature increases the compressive strength reduced 11 and 19 % after heat exposure at 100 and 200 ℃, respectively. Moreover, the increasing of PS replacement level lead to a decrease in the compressive strength, where the lowest strength value of 18.52 MPa was after heating at 200 ℃. Furthermore, when the temperature reaches 200 ℃ lead to more evaporation of water from the concrete specimens which caused a significant decrement in compressive strength values.

GLENIUM 27 has an important role. When the percentage of GLENIUM 27 decreased from 1.75 % to 1.5 % with 60 % PS replacement level, the increased percentage of compressive strength before heating was 16 %, and after heating at 100 and 200 ℃ was 13 % and 28 % respectively.

Table 4. 9: Compressive Strength Test Results Test Results of PS-SCC Concrete before and after Heat Exposure at 100 and 200 ℃

Type of PS-SCC Mixture	Compressive Strength (MPa)		
	Before heating (MPa)	After heating at 100℃	After heating at 200℃
SCC0PS	75.5	67.35	61.3
SCC20PS	57.5	51.15	38.3
SCC40PS	46.133	44.2	33.9
SCC60PS with 1.75 % of G	28.67	22.13	18.52
SCC60PS with 1.5 % of G	33.27	28.93	23.915

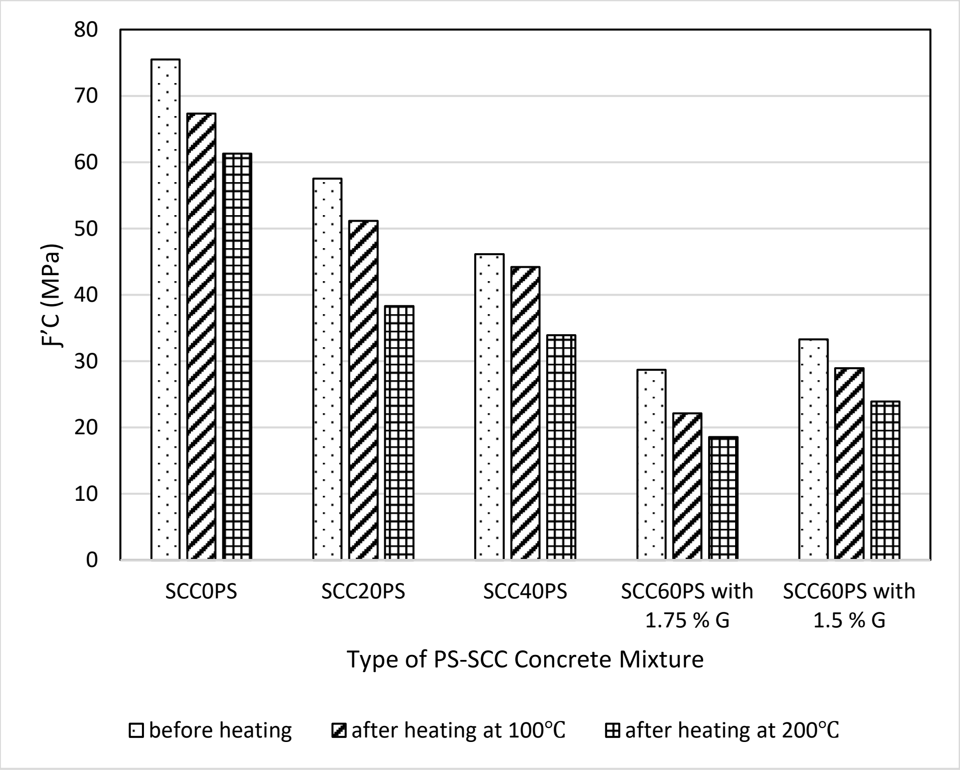


Figure 4.13: Compressive Strength Test Results of PS-SCC before and after Heat Exposure at 100 And 200 ℃

4.8.4 The Effect of High Temperature on the Splitting Tensile Strength of PS-SCC

The temperature has a greater influence on splitting tensile strength depending on the different percentages of PS replaced by volume of coarse aggregate. Table 4.10 and Figure 4.14 appeared that splitting tensile strength decreases with increasing temperature. Moreover, when specimens were exposed to higher temperatures, the splitting tensile strength appeared similar behavior to the significant losses in compressive strength. splitting tensile strength is more sensitive to elevated temperature through the values indicated by the results due to compressive strength (Obeed, 2007). Note that the splitting tensile strength reduced when the temperature increased. For example, at 20 % splitting tensile strength was 3.81 MPa before heating and decreased to 3.76 MPa after heating at 100 ℃. The lowest splitting tensile strength was 3.62 MPa after heating at 200 ℃. This applies to all the ratios from 0 % PS to 60 % PS.

It is worth mentioning that GLENIUM 27 has an influence on splitting tensile strength. The reduction of GLENIUM 27 from 1.75 to 1.5 % at 60 % PS replacement level increased the splitting tensile strength from 2.65 to 2.71 MPa before heating and continued to reduce 7 and 16 % after heating at 100 and 200 ℃, respectively.

Table 4.10: Splitting Tensile Strength Test Results of PS-SCC before and after Heat Exposure at 100 And 200 ℃

Type of PS-SCC Mixture	Splitting Tensile Strength (MPa)		
	Before heating (MPa)	After heating at 100℃	After heating at 200℃
SCC0PS	4.339	4.255	3.79
SCC20PS	3.81	3.76	3.62
SCC40PS	3.95	3.83	3.75
SCC60PS with 1.75 % of G	2.65	2.27	2.24
SCC60PS with 1.5 % of G	2.71	2.53	2.28

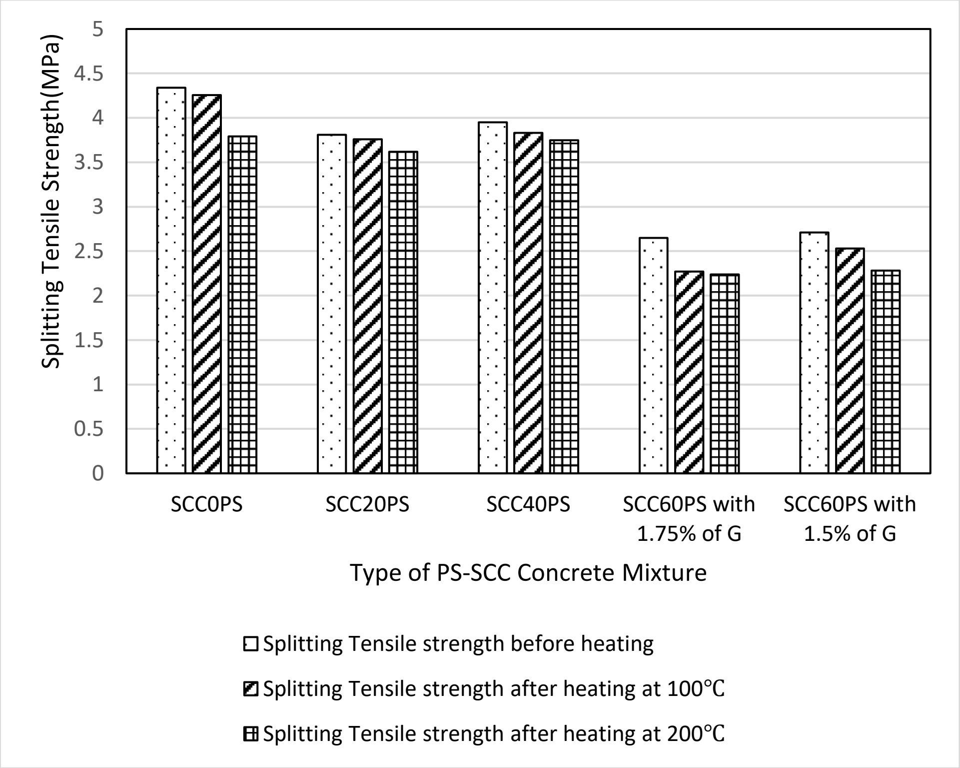


Figure 4.14: Splitting Tensile Strength Test Results of PS-SCC before and after Heat Exposure at 100 and 200 ℃

4.8.5 Relationship between Compressive and Splitting Tensile Strength of PS-SCC Concrete

Table 4.11 and Figure 4.15 present the relationship between splitting tensile and compressive strength prior and after exposure to heat at 100 and 200 ℃. From Figure 4.15 it can be observed that as the compressive strength reduces splitting strength also reduces.

Table 4.11: Relationship between Splitting Tensile and Compressive Strength of PS-SCC before and after Exposure to Heat

Concrete type	**Regretion type**	**Equation before heatting**	**R^2**	**Equation after heatting at 100℃**	**R^2**	**Equation after heatting at 200℃**	**R^2**
PS-SCC	Exponential	$y = 2.0257e^{0.0109x}$	0.8174	$y = 1.7273e^{0.0146x}$	0.8892	$y = 1.9232e^{0.0131x}$	0.6281
	Linear	$y = 0.037x + 1.7092$	0.8383	$y = 0.0464x + 1.3465$	0.9111	$y = 0.0386x + 1.7781$	0.6352
	Logarithmic	$y = 1.8363\ln(x) - 3.5109$	0.8939	$y = 1.913\ln(x) - 3.7088$	0.9547	$y = 1.529\ln(x) - 2.1783$	0.7643
	Polynomial	$y = -0.0008x^2 + 0.1205x - 0.2115$	0.9127	$y = -0.0008x^2 + 0.12x - 0.0679$	0.9654	$y = -0.0019x^2 + 0.1916x - 0.8546$	0.8992
	Power	$y = 0.4305x^{0.5436}$	0.8833	$y = 0.3427x^{0.6098}$	0.9493	$y = 0.5003x^{0.5198}$	0.7602

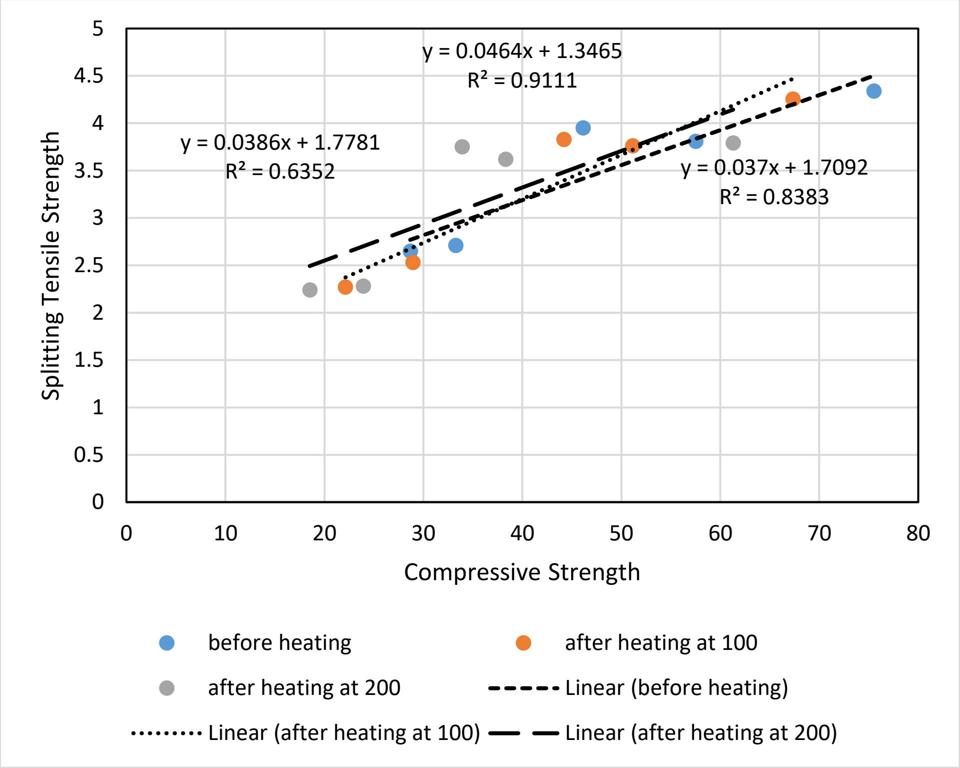


Figure 4.15: Relationship between Splitting Tensile and Compressive Strength of PS-SCC Concrete before and after Exposure to Heat

4.8.6 Relationship between Splitting Tensile Strength and UPV of PS-SCC

Table 4.12 and Figure 4.16 shows the relationship between UPV and splitting tensile strength before and after heating at 100 and 200 °C. As it can be seen from Figure 4.16, as UPV decreased splitting tensile strength also decreased.

Table 4.12: Relationship between UPV and Splitting Tensile Strength before and after Exposure to Heat for PS-SCC

Concrete type	Regretion type	Equation before heatting	R^2	Equation after heatting at 100°C	R^2	Equation after heatting at 200°C	R^2
PS-SCC	Exponential	$y = 0.1383e^{0.6989x}$	0.1848	$y = 1.436e^{0.1884x}$	0.0316	$y = 0.0167e^{1.377x}$	0.6642
	Linear	$y = 2.5303x - 8.1247$	0.2148	$y = 0.5708x + 0.8724$	0.0296	$y = 4.0376x - 12.139$	0.6636
	Logarithmic	$y = 11.685\ln(x) - 14.313$	0.2119	$y = 2.5888\ln(x) - 0.4455$	0.0333	$y = 15.423\ln(x) - 17.374$	0.671
	Polynomial	$y = 22.24x^2 - 204.4x + 472.78$	0.3363	$y = -18.498x^2 + 159.15x - 337.98$	$R^2 = 0.5293$	$y = -13.974x^2 + 110.29x - 213.83$	$R^2 = 0.7626$
	Power	$y = 0.025x^{3.2271}$	0.1822	$y = 0.9306x^{0.8536}$	$R^2 = 0.0354$	$y = 0.0028x^{5.2607}$	0.6719

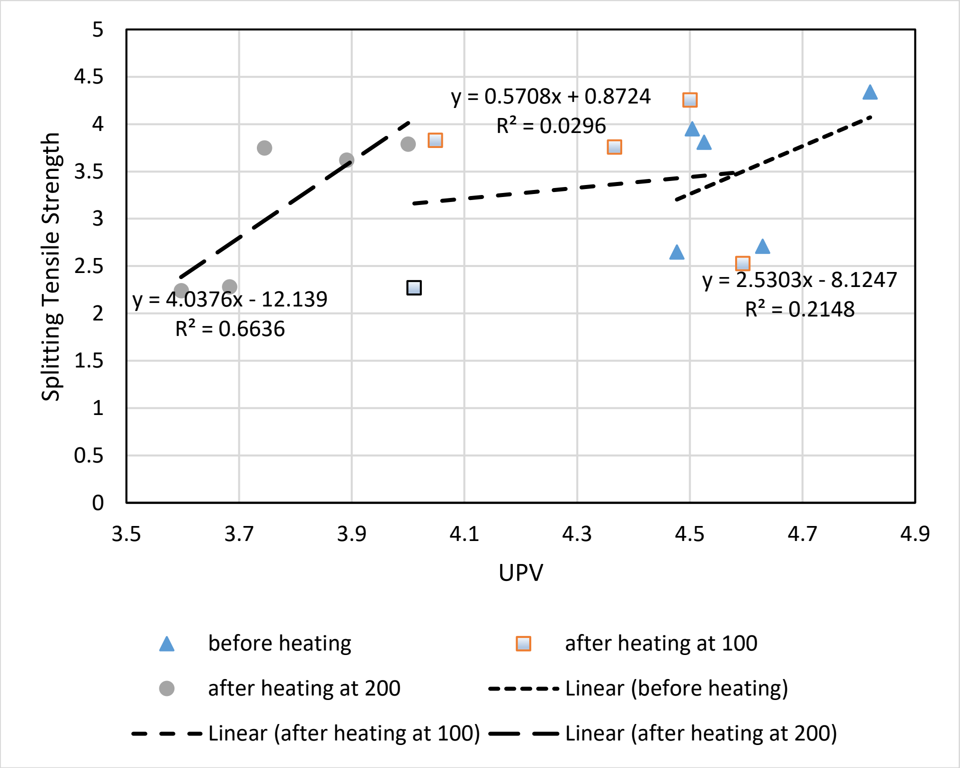


Figure 4.16: Relationship between UPV and Splitting Tensile Strength before and after Exposure to Heat

4.8.7 Relationship between UPV and Compressive Strength of PS-SCC

Table 4.13 and Figure 4.17 show the relationship between UPV and compressive strength before and after heating at 100 and 200 ℃. In general, from Figure 4.17, it can be observed that the UPV increases as the compressive strength increases.

Table 4.13: Relationship between Compressive Strength and Ultrasonic Pulse Velocity (UPV) before and After Heating for PS-SCC

Concrete type	**Regression type**	**Equation before heating**	**R^2**	**Equation after heating at 100℃**	**R^2**	**Equation after heating at 200℃**	**R^2**
PS-SCC	Exponential	$y = 0.0129e^{1.7775x}$	0.3999	$y = 2.7872e^{0.6167x}$	0.1326	$y = 0.0009e^{2.7589x}$	0.9478
	Linear	$y = 94.876x - 387.36$	0.4925	$y = 25.221x - 65.795$	0.1365	$y = 98.088x - 335.9$	0.9182
	Logarithmic	$y = 439.49\ln(x) - 621.45$	0.4887	$y = 110.79\ln(x) - 118.77$	0.1438	$y = 371.68\ln(x) - 459.09$	0.9137
	Polynomial	$y = 460.61x^2 - 4190.7x + 9572.3$	0.5775	$y = -362.24x^2 + 3130.7x - 6701.5$	0.5888	$y = 142.13x^2 - 982.67x + 1715.6$	0.9422
	Power	$y = 0.0002x^{8.2374}$	0.3972	$y = 0.7583x^{2.7131}$	0.14	$y = 3E-05x^{10.484}$	0.9485

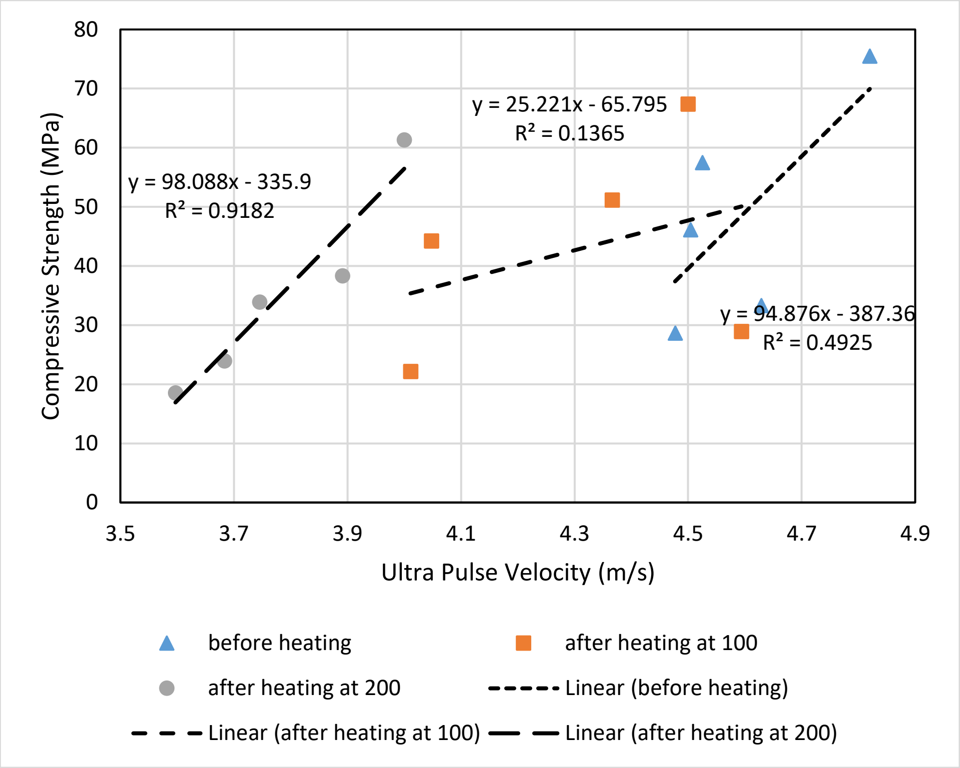


Figure 4.17: Relationship between UPV and Compressive Strength before and after Exposure to Heat

4.8.8 Observations After Exposure of PS-SCC to High Temperatures

At high temperatures cracks seemed on the surface of samples as shown in the Figure 4.18 and 4.19. The loss of strength indicate that exposure to high temperatures weakens the concrete and increase the pores rate because of the loss of water during heating. At 200 °C the PS on the top was burnt completely and the specimens color changed from gray to brown color.

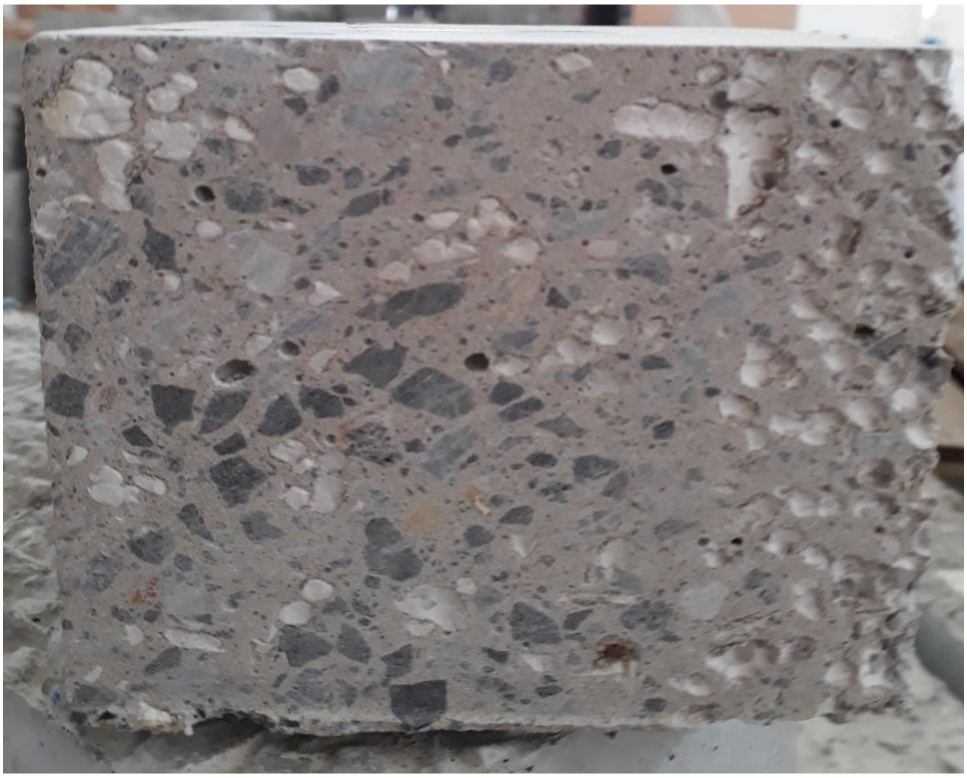
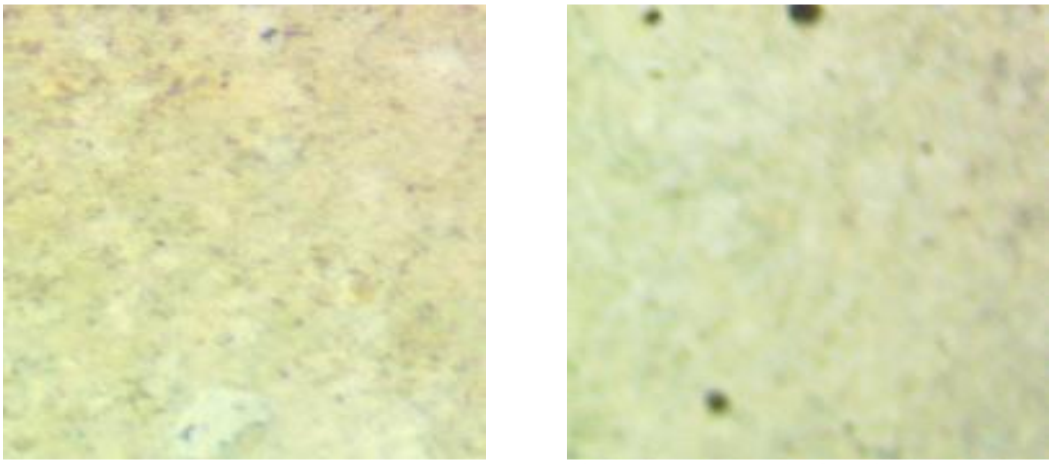


Figure 4.18: PS-SCC Specimen after Heat Exposure at 100 ℃

Figure 4.19: PS-SCC Specimen after Heat Exposure at 200 ℃

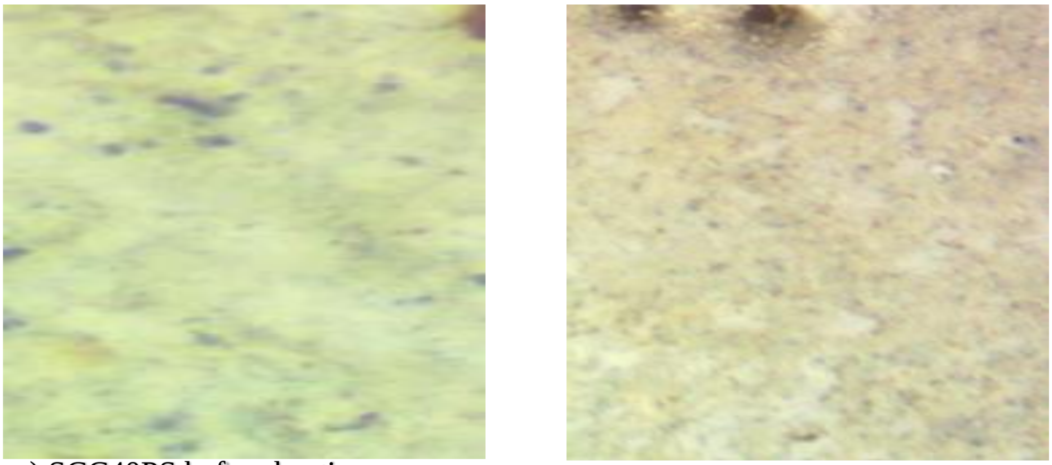
4.8.9 Stereo-Microscopic Observation of Cracks after Exposure of PS-SCC to High Temperatures

Figures 4.20, 4.21, 4.22 shows the effect of temperature on surface of specimens with different percentages 0, 20, 40 and 60 % with 1.75 % G, 60 % with 1.5 % G of PS as a replacement by volume of normal coarse aggregate. It turned out that after the specimens were placed in the oven at 200 ℃, temperature did not affect in actual meaning and no cracks were seen on the surface of specimens by using Stereo-microscope, this is also applied to control specimens. Moreover, this indicates that the heat is insufficient on the surface of specimens, perhaps a temperature above 200 ℃ is required to cause cracks.



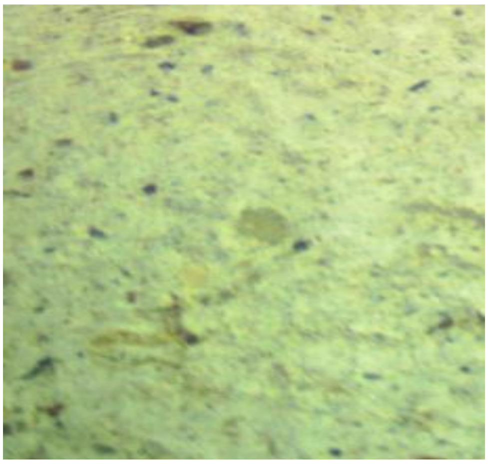
a) SCC0PS befor heating

b) SCC20PS at before heating



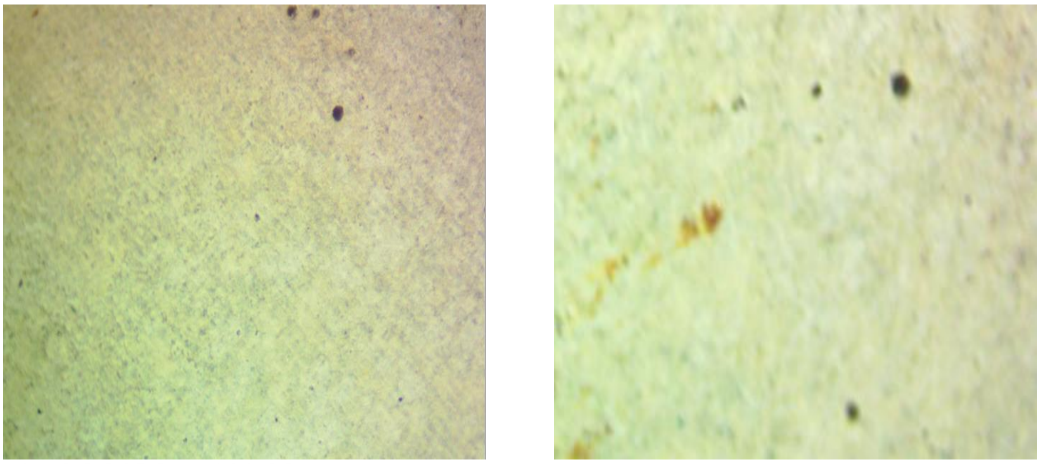
c) SCC40PS before heating

d) SCC60PS with 1.75 % G before heating

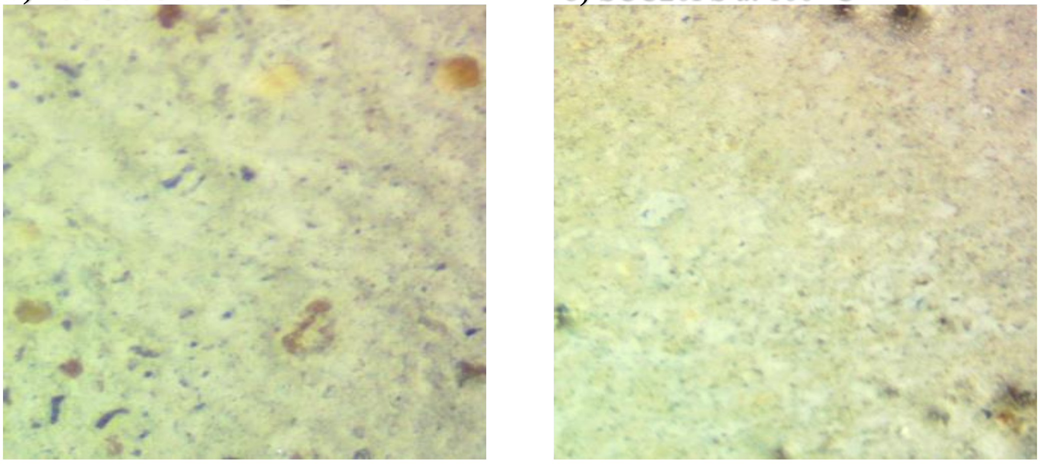


e) SCC60PS with 1.5 % G before heating

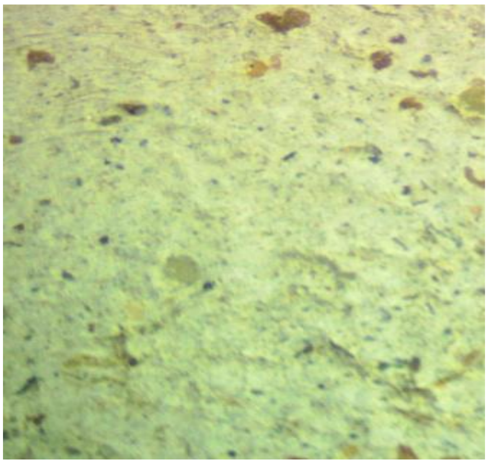
Figure 4.20: Stereo-Microscopic Observations of PS-SCC before Heat Exposure



a) SCC0PS at 100 ℃ b) SCC20PS at 100 ℃

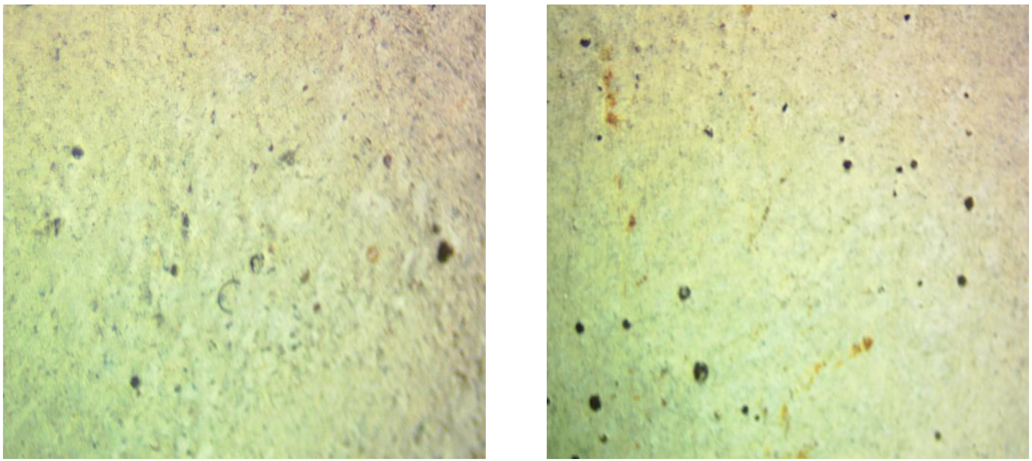


c) SCC40PS at 100 ℃ d) SCC60PS with 1.75 % G at 100 ℃



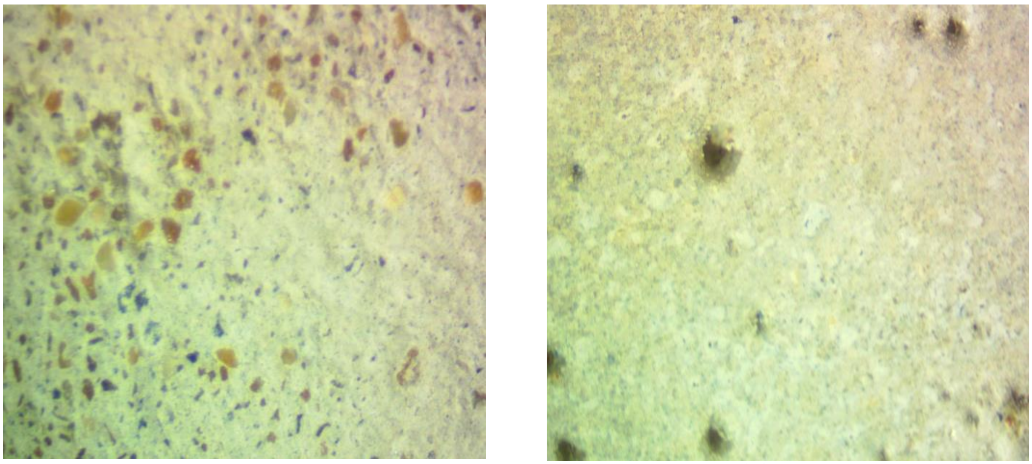
e) SCC60PS with 1.5 % G at 100 ℃

Figure 4.21: Stereo-Microscopic Observations of PS-SCC after Heat Exposure at 100 ℃



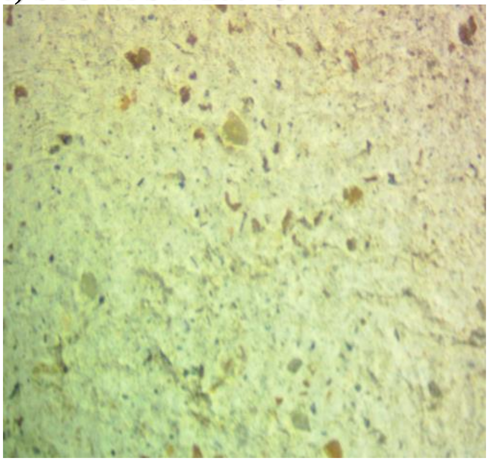
a) SCC0PS at 200 °C

b) SCC20PS at 200 °C



c) SCC40PS at 200 °C

d) SCC60PS with 1.75 % G at 200 °C



e) SCC60PS with 1.5 % G at 200 °C

Figure 4.22: Stereo-Microscopic Observations of PS-SCC after Heat Exposure at 200 °C

4.9 Flexural Toughness Tests Obtained from Load-Deformation Diagrams

In order to measure the effect of different percentages of PS on flexural strength of beams samples, fifteen beams were tested at 28 days of curing. The results are seen in Table 4.14 below.

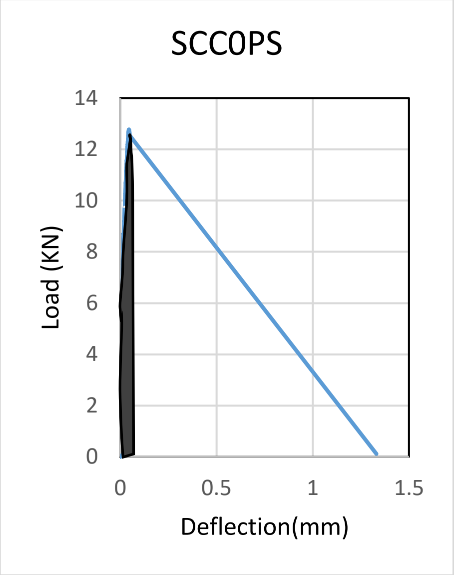
Whenever the percentages of PS increased, the maximum load reduced by 45 %. The control beam specimens had the highest strength 11.493 (MPa). It can be clear in Figure 4.24, that flexural strength decreased with increasing PS, the loss of strength as the beams began to weaken until it reached its lowest was about 45 %.

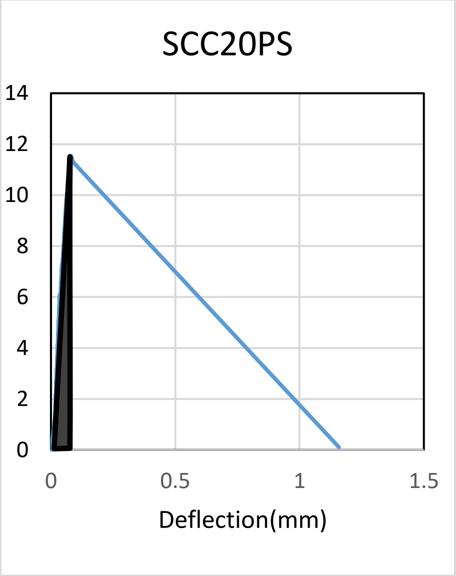
In addition, GLENIUM 27 had an impact on the flexural strngth, when it decreased from 1.75 to 1.5 % with 60 % PS, the strength of beams returned and increased 23 %.

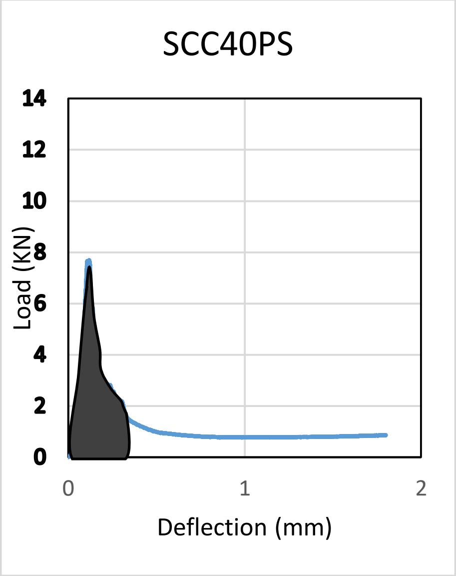
According to the Figures 4.23, the minimum to maximum area of toughness depended on each percentage because when the percentage of PS increased, the area of toughness increased. However, when the percentage of GLENIUM 27 reduced to 1.5 %, the area of toughness decreased.

Table 4.14: Maximum Load and Flexural Strength Test Results of PS-SCC Concrete

Type of PS-SCC Mixture	**Maximum Load**	**Flexural Strength (MPa)**
SCC0PS	12.77	11.493
SCC20PS	11.48	10.33
SCC40PS	7.65	6.885
SCC60PS with 1.75 % G	7.096	6.3864
SCC60PS with 1.5 % G	8.69	7.821


SCC0PS
Load (KN)
14
12
10
8
6
4
2
0
0
0.5
1
1.5
Deflection(mm)


SCC20PS
14
12
10
8
6
4
2
0
0
0.5
1
1.5
Deflection(mm)


SCC40PS
Load (KN)
14
12
10
8
6
4
2
0
0
1
2
Deflection (mm)

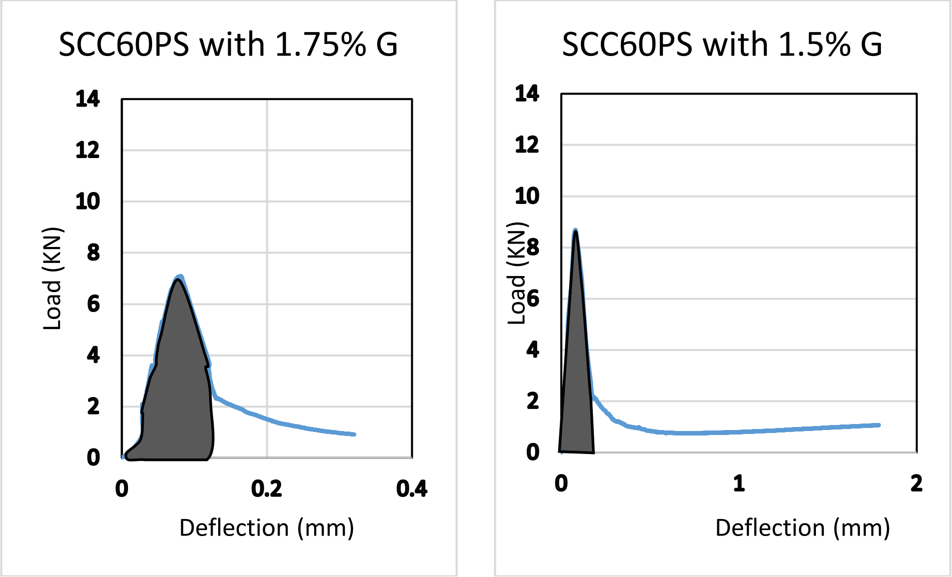


Figure 4.23: Effect of Different Proportions of PS on Load–Deflection Diagrams of SCC

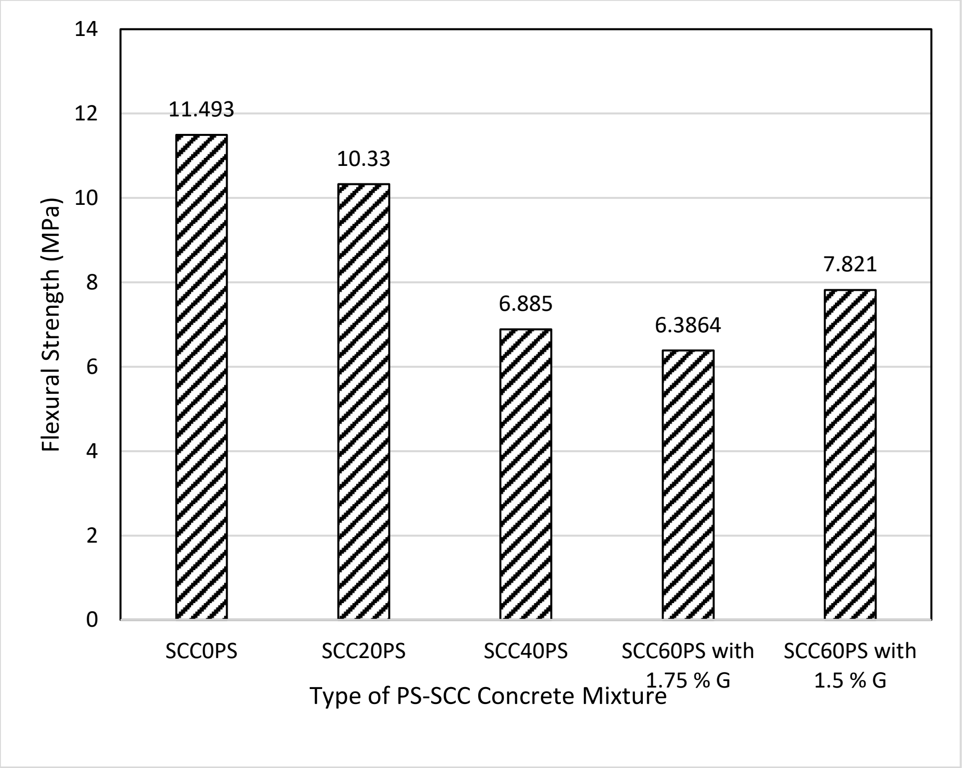


Figure 4.24: Effect of PS on Flexural Strength of PS-SCC

4.10 Relationship between Splitting Tensile Strength, Compressive Strength and Flexural Strength

Table 4.15 and 4.16 present various regression relationships with their regression coefficients (R^2). The best relationship of concrete for 28 days can be observed with respect to regression coefficient R^2. Figure 4.26 presents the relationship between compressive and splitting tensile strength of concrete. It also emphasizes that when the compressive strength decreased the splitting tensile strength also decreased.

Figure 4.25 show the relationship of compressive strength with flexural strengthof PS-SCC concretes. As it can be shown from Figure 4.20 when the flexural strength decreased compressive strength also decreased.

Table 4.15: Various Relationships between Compressive and Flexural Strength for PS-SCC

Concrete type	Regression type	Equation	R^2
PS-SCC	Exponential	$Y = 5.0279e^{0.0125x}$	0.6491
	Linear	$Y = 0.1094x + 4.1352$	0.6538
	Logarithmic	$Y = 3.6285\ln(x) - 4.5704$	0.5868
	Polynomial	$Y = 0.0034x^2 - 0.1498x + 8.4012$	0.7307
	Power	$Y = 1.8264x^{0.4196}$	0.5962

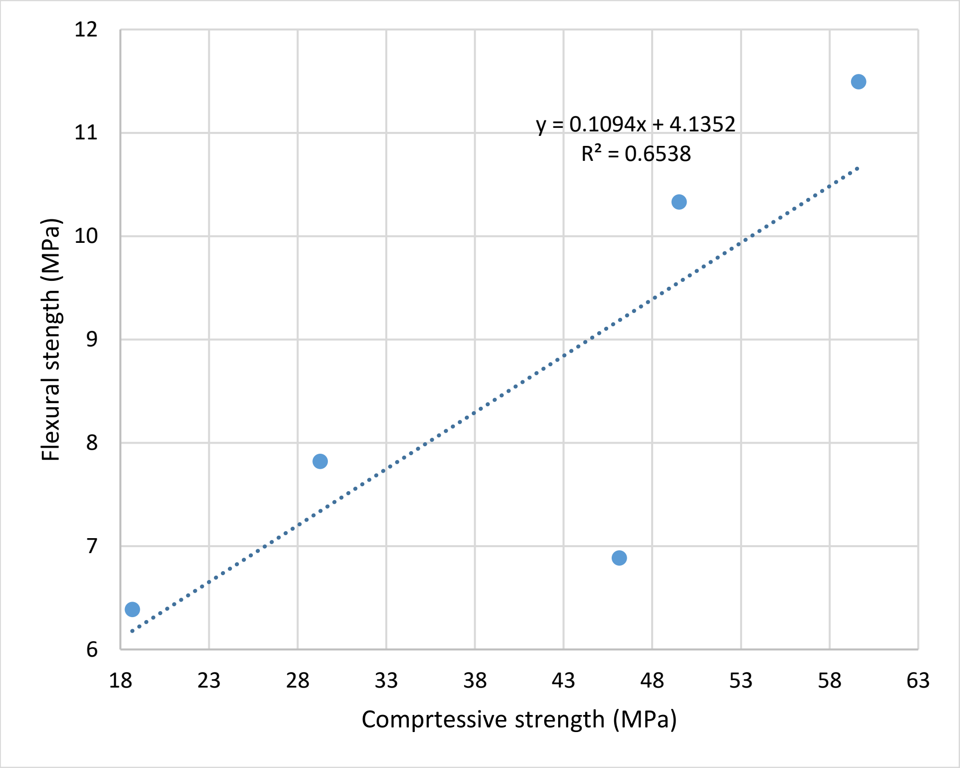


Figure 4.25: Relationship between Flexural Strength and Compressive Strength for PS-SCC

Table 4.16: Various Relationships between Compressive Srength and Splitting Tensile Strength for PS-SCC

Concrete type	**Regression type**	**Equation**	**R^2**
PS-SCC	Exponential	$y = 2.1525e^{0.0123x}$	0.7211
	Linear	$y = 0.0458x + 1.774$	0.7213
	Logarithmic	$y = 1.4434\ln(x) - 1.5966$	0.5847
	Polynomial	$y = 0.0023x^2 - 0.135x + 4.7499$	0.9571
	Power	$y = 0.866x^{0.3894}$	0.5871

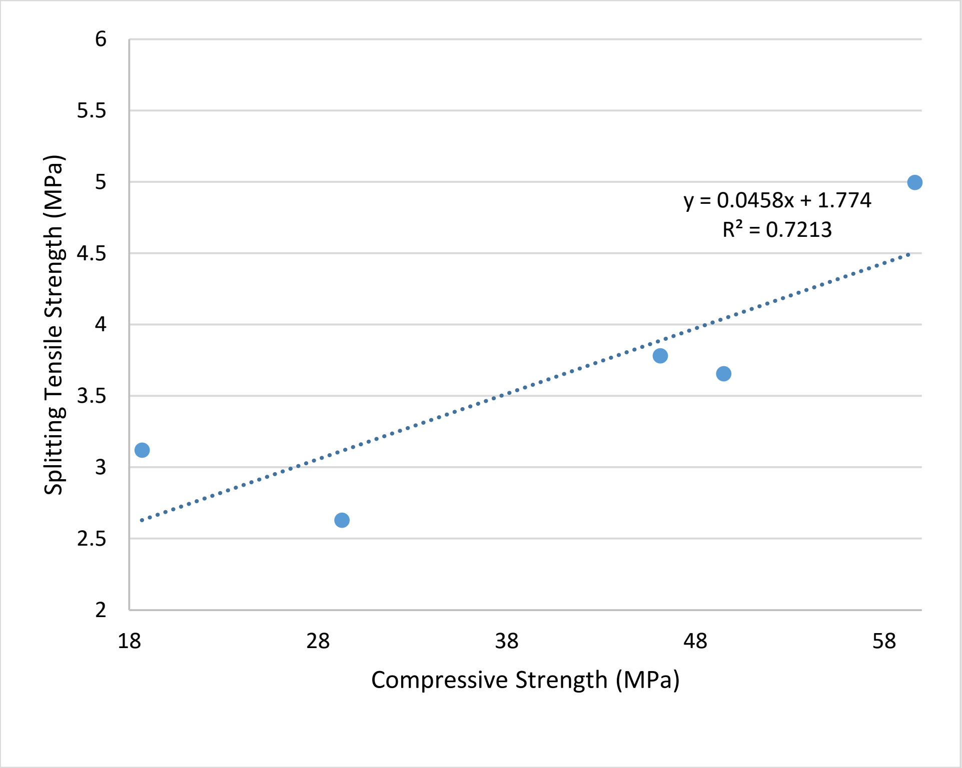


Figure 4.26: Relationship between Compressive Strength and Splitting Tensile Strength of PS-SCC

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this experimental study, five different percentages namely 0, 20, 40, 60 % with 1.75 % G and 60 % with 1.5 % G of PS utilized as a partial by the volume with normal crushed limestone coarse aggregate. It investigates the impact of PS on the mechanical and physical properties of SCC. According on the test results obtained from this study, the following conclusions are withdrawn:

1. PS has a positive effect on workability. As the replacement percentages of PS increases, the workability increases. Therefore, it is possible to produce SCC concrete by using PS.
2. PS has a negative effect on compressive strength, the high level of Polystyrene in concrete leads to weakening the compressive strength.
3. Partial PS replacement with crushed aggregate at 40 % improved the splitting tensile strength. However, more or less than 40 % reduced the splitting tensile strength.
4. Heat exposure on the samples had a negative effect on weight, UPV, splitting tensile strength and compressive strength.
5. Regarding the experiment results of flexural strength, it can be said that the increasing of PS ratio adversely affect the flexural strength of beam specimens.
6. PS material proved by toughness test that it is a coherent material because ductility was satisfied.

7. Because of low melting point of PS, when the specimens were exposed to high temperature in the oven at 200 ℃, there were no cracks in all specimens.
8. The superplasticizer GELENIUN 27 plays an important role in all tests; by increasing the percentage of GELENIUM 27 from 1.75 % to 1.5 %, this reduction has a positive effect on the mechanical and physical properties of PS-SCC.
9. As the V-Funnel test increased, Slump flow test and L-Box test increased.
10. As the splitting tensile strength decreased, the compressive strength decreased.
11. As the UPV reduced, splitting tensile strength and compressive strength reduced.
12. As the flexural strength decreased, splitting tensile and compressive strength also decreased.

5.2 Recommendations

1. Utilizing more accurate percentages of PS as an aggregate replacement material in order to arrange and determine the exact ultimate replacement percentage according to each mechanical and physical properties.
2. This study was performed using aggregate replacement materials. Usage of different pozzolans could be replaced by other materials for example fine aggregate.
3. This experimental study has two different percentages of GLENIUM 27. It could be also worth to study the effect of the superplasticizer on the PS-SCC concrete at lower percentages of GLENIUM 27.
4. Studying the effect of PS on the permeability test.
5. Studying the shrinkage and creep properties of PS–SCC

6. Studying properties of PS–SCC at elevated temperatures especially above 200 ℃.

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