Effect of High Density Polyethylene Plastic (HDPE) and W/C Ratio on Fresh and Hardened Properties of Self-Compacting Concrete

Abdul Hadi H .E. Alzaylaa

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Assoc. Prof. Dr. Ali Hakan Ulusoy
Acting Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science in Civil Engineering.

Assoc. Prof. Dr. Serhan Şensoy
Chair, Department of Civil Engineering

We certify that we have read this thesis and that in our opinion it is fully adequate in scope and quality as a thesis for the degree of Master of Science in Civil Engineering.

Assoc. Prof. Dr. Khaled Marar
Supervisor

Examining Committee

1. Assoc. Prof. Dr. Ertuğ Aydın
2. Assoc. Prof. Dr. Khaled Marar
3. Asst. Prof. Dr. Tülin Akçaoğlu

ABSTRACT

In this thesis, the effects of High Density Polyethylene (HDPE) aggregates are studied on fresh and hardened properties of self-compacted concrete (SCC). Therefore, 5 different replacement levels of HDPE with coarse aggregate namely 0 %, 5 %, 10 %, 20 %, and 30 % by volume. In addition, superplasticizer (Glenium 27) and silica fume were added to SCC mixtures by 1.7 % and 10 % by weight of binder, respectively. Slump flow, L-box, and V-funnel tests were performed on the 5 different mixtures to study the workability of SCC. Compressive strength, splitting tensile strength, flexural strength and toughness tests were utilized to study the mechanical properties of the SCC mixtures, while plastic degradation at 100 and 200 °C temperatures, ultra-sonic pulse velocity, and surface cracks observations to determine the durability of the SCC mixtures. After these tests are performed, the results reveal that it is possible to produce self-compacted concrete using HDPE up to 30% replacement level. However, incorporation of HDPE in self-compacted concrete has negative effects on the properties of SCC, decrement in workability, compressive strength, splitting tensile strength, flexural strength, UPV, and it causes surface cracks. On the hand, adding HDPE in SCC has positive effects as well, since it increases the ductility of SCC, and reduces the self-weight of concrete which is promising to produce light-weight concrete.

Keywords: high density polyethylene (HDPE), self-compacting concrete (SCC), silica fume, workability, mechanical properties, compressive strength, splitting tensile strength, ultrasonic pulse velocity (UPV), flexural strength, toughness.

ÖZ

Bu tezde, kendiliğinden yerleşen betonun (KYB) taze ve sertleşmiş beton özelliklerinde; iri agreganın yüksek yoğunluklu polietilen (YYPE) ile % 0, % 5, % 10, % 20 ve % 30 oranlarında ikame ettirilmesi neticesinde oluşan değişiklikler araştırılmıştır. Ek olarak, süper akışkanlaştırıcı (Glenium 27) ve silis dumanı KYB karışımına sırasıyla ağırlıkça % 1.7 ve % 10 bağlayıcı olarak ilave edilmiştir. KYB işlenebilirlik (çökme değeri, V-hunisi ve L-box) şartları, YYPE agrega ile % 30 miktarı kadar yer değiştirmesi ile sağlanmıştır. KYB karışımlarının mekanik özelliklerini incelemek için basınç dayanımı, yarmada gerilme mukavemeti, eğilme dayanımı ve tokluk testleri yapılırken, 100 ve 200 °C sıcaklıklarda plastik bozulma, ultrasonik hız değişimi ve yüzey çatlakların mikroskop analizi dayanıklılık özeliklerini belirlemek için yapılmıştır. Bu testler yapıldıktan sonra, sonuçlar, % 30'a varan oranlarda YYPE kullanılarak kendiliğinden sıkıştırılmış beton üretmenin mümkün olduğunu ortaya koymaktadır. Elde edilen sonuçlara göre, YYPE’nin farklı oranlarda iri agrega yerine kullanılması betonun fiziksel ve mekanik özeliklerinde birtakım değişikliklere yol açmıştır. Özellike sünekliğin arttığı, beton basınç dayanımı ve de yoğunluğunun azaldığı saptanmıştır. Elde edilen KYB’da YYPE'nin eklenmesi, KYB'nun sünekliğini arttırdığı ve hafif beton üretmeyi olanaklı kıldığı için olumlu etkilere de sahiptir.

Anahtar Kelimeler: yüksek yoğunluklu polietilen (YYPE), kendiliğinden yerleşen beton (KYB), işlenebilirlik, mekanik özellikler, basınç mukavemeti, yarma mukavemeti ultrases geçiş hızının tayini (UGHT), eğilme mukavemeti, dayanıklılık, silis dumanı.

DEDICATION

Deeply in my heart, I’d like to devote this work to all people who supported me all along in my career. Special thanks for my mother and father who stood beside me in all hard time

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LIST OF SYMBOLS AND ABBREVIATIONS

C	Cement
CA	Coarse Aggregate
FA	Fine Aggregate
f_c'	Compressive Strength
f_{st}	Splitting Tensile Strength
f_f	Flexural Strength
f_t	Tensile Strength
HDPE	High Density Polyethylene
ITZ	Interfacial Transition Zone
SCC	Self-Compacted Concrete
SCC00HDPE	0 % HDPE Aggregate Replacement Level in SCC
SCC05HDPE	5 % HDPE Aggregate Replacement Level in SCC
SCC10HDPE	10 % HDPE Aggregate Replacement Level in SCC
SCC20HDPE	20 % HDPE Aggregate Replacement Level in SCC
SCC30HDPE	30 % HDPE Aggregate Replacement Level in SCC
SF	Silica Fume
SP	Superplasticizer
W	Water
W/b	Water Binder Ratio
UPV	Ultrasonic pulse velocity

Chapter 1

INTRODUCTION

1.1 Background of the Research

One of the most significant inventions of the 20th century is plastic. All over the world, plastic consumption has shown substantial growth, leading to huge increase in plastic related waste. The increase in consumption of plastic shows no sign of declining mostly due to urbanization, consequently leading to an inevitable increase in plastic related waste. According to the United Nations, plastic waste is considered to a serious environmental threat to modern civilization that is most likely to have significant impact in the ecosystem.

The production of plastic involves the combination of several toxic chemicals which inherently will pollute air, water and soil (Saikia & de Brito, 2012). Plastic is a non-biodegradable material, therefore land-filling plastics conserve the harmful materials of plastics forever. There are numerous hazards associated to plastic waste which includes:

- Blocking of drainage system in city:- blocked drainage provides habitat for disease carrying organisms and causes flooding.
- Reduction of rainwater percolation
- Reduction of soil fertility:- the permanent storage of plastic-waste chemicals affects the soil fertility.

- Contamination of rivers, seas, streams and marine life: consumption of plastic by aquatic animals can damage their health

As the threat of plastic waste continuous to increase globally, countries are restricting the use of plastic bags and other plastic materials. Since burning plastics releases various poisonous chemicals, recycling plastics is a more favourable option. Plastics can be used to produce new plastic based products, however it is a not an economical process (Saikia & de Brito, 2012). The use of plastic waste to produce new materials such as cement composite presents it's self as the best option for disposing plastic waste because it has both ecological and economic advantages.

Reusing of the continuous supply of plastic waste will help preserves the environment, and utilizing high density polyethylene as an aggregate in concrete mixtures serves as other plastic wastes such as poly vinyl chloride (PVC) pipe (Kou, Lee, Poon, & Lai, 2009) and thermosetting plastics (Panyakapo & Panyakapo, 2008) both improves the environment and the construction industry economically and environmentally.

1.2 Problem Statement

About 10 % of greenhouse gases are emitted by the cement manufacturing industry. And the cement manufacturing industry is the most fundamental part of the construction industry. Therefore, improving the properties of construction process which uses cement as of its main materials minimizes greenhouse gases emission. In addition, minimizing the effects of plastic waste by utilizing it as composite material in construction decreases water, air and land pollution caused by plastic wastes. The environmental and economic problems from plastic waste disposal can be minimized by implementing more environmental friendly technologies such as using plastic waste a component of mixture concrete.

1.3 Aim of Research

The use of plastic waste such as HDPE in concrete has both economic and environmental benefits. The economic benefits refer to the reduction of total construction cost, and the environmental benefits includes reduction of HDPE plastic waste which causes serious environmental pollution. Studies such as (Hınıslıoğlu & Ağar, 2004) have investigated the use of HDPE in concrete. In this thesis, the effects of using plastic HDPE on fresh and hardened self-compacted concrete (SCC) is investigated. To achieve the objectives of the thesis, SCC with and without HDPE will be tested. The coarse aggregate of SCC is replaced with HDPE at different levels namely 0, 5, 10, 20 and 30 %. The effects will be tested and conclusion will be drawn.

1.4 Methodology

The goals of the thesis are achieved by creating five different mixtures of self-compacting concrete (SCC) at different percentages replacement for coarse aggregate with HDPE and with a constant water/binder (w/b) ratio of 0.45. Recycling of HDPE is achieved as a partial replacement levels for coarse aggregate in concrete at 0, 5, 10, 20 and 30 %. The chemical, physical and mechanical properties of the test specimens are investigated by performing multiple tests such as: splitting tensile strength (f_{st}), compressive strength (f_c'), flexural strength (f_f), ultrasonic pulse velocity (UPV) and heat exposure tests at 100 and 200 °C.

1.5 Thesis Outline

In writing the thesis, the chapters are organized as follows: Chapter 2 presents the literature review and the related experiments that have used plastic wastes as aggregates in concrete including HDPE in SCC. Chapter 3 discusses the experimental works in details showing the methods and using appropriate standards. The results and discussion of the experimental works are presented in Chapter 4. Conclusions of the thesis are made in Chapter 5 with recommendations for future studies.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

In the construction industry, the most widely used material is concrete. The quantity of concrete used is twice the amount of other materials including aluminium, wood and plastics. Therefore, it is important to improve the concrete mixture because it contributes to the future of the construction industry.

The need for alternative concrete mixture materials in the construction industry stems from the need of improved structures and concrete properties, environmental considerations and economic impact such as cost effectiveness in construction. Therefore, the use of materials that improve concrete properties such as concrete stability by improving the physical, chemical and mechanical properties, and simultaneously serve the environment and have economic benefits are imperative.

Replacing coarse aggregate with plastic such as HDPE is an attractive technique. The use of HDPE as a component of mixture concrete has been experimented by (Panyakapo & Panyakapo, 2008).

Another important property is thermal-insulation in structures. Replacing coarse aggregate with plastic such as HDPE or expanded polystyrene has emerged as a method for improving thermal-insulation properties. (Ferrándiz-Mas, Bond, García-

Alcocel, & Cheeseman, 2014) developed a lightweight concrete using expanded polystyrene as a concrete component. They proposed the use of 20 % paper sludge and 60 % expanded polystyrene in the cement mortar. The usage of such environmental waste has both structural and environmental benefits.

Fibre reinforced concrete has been introduced as a way of utilizing plastic. This has favourable properties such as improving in flexural toughness and ductility, shrinkage, tensile fatigue strength and resistance to explosive spalling at high temperature. This has been applied in various structures such as foundation slabs, pavement to bridges, industrial floors and tunnels (Pešić, Živanović, Garcia, & Papastergiou, 2016). The benefits of using plastic fibres are limited to improvement of concrete serviceability properties such as impact resistance and post cracking ductility.

The use of recycled plastic is an attractive innovation. The economic incentive in the construction industry has the potential of increasing the production of recycled plastic as a substitute to polypropylene. As a substitute is the use of low density polyethylene (Alhozaimy & Shannag, 2009). This has the advantage of reducing plastic shrinkage cracking. The use of recycled polyethylene terephthalate was tested but found to have degradation properties when exposed to alkalinity of concrete (Fernando, Montedo, Gleize, & Roman, 2012; Silva et al., 2005).

Another candidate of recyclable polymer that can be used for mass production is HDPE. HDPE has similar physical and chemical properties to poly-propylene such as low bond strength between high density polyethylene and concrete due to the textured and ribbed surface (Pešić et al., 2016).

The use of HDPE was first shown by (Kobayashi & Cho, 1981). They used it to increase the post cracking flexural toughness and ductility of concrete. (Soroushian, Khan, & Hsu, 1992) found that HDPE has similar mechanical properties such as impact resistance to that of polypropylene and high-modulus polyethylene fibre.

The early application of HDPE did not lead to continuous use of the plastic in the construction industry. Later, a concrete specimen of 0.2 - 1.0 % volume fraction of HDPE from waste plastic vessels was used by (Bhavi, Reddy, & Ullagaddi, 2012). The result from their experiment showed that at 0.6 % HDPE volume, the tensile, compressive, and flexural and impact strength of the concrete can be enhanced by up to 23, 15, 22 and 20 %, respectively. They noticed only modest increase in the properties at 0.8 and 1.0 %.

In a review of most recent subject of concrete reinforced with synthetic fibres/polymers, (Yin et al., 2015) highlighted the need for more research on the benefits and properties of using HDPE in concrete.

2.2 Components of Concrete

Concrete consists of cement, water, sand, gravel, chemical and mineral admixtures. The gaps between coarse aggregate are filled by mortar, and the gap between fine aggregate are filled by paste. The composition of paste include cement, water, minerals, chemical mixtures which include (water reducing admixtures and viscosity modifiers) including air (Li et al., 2017) as mentioned earlier, research in the area of concrete performance improvement includes replacing the fine and coarse aggregate with other minerals and plastic waste.

Plastics are used in mainly two forms in concrete (i) plastic fibres used as reinforce concrete, (ii) plastic aggregates. The use of plastic aggregate in concrete is mostly used for manufacturing light weight concrete because of the bulk density of plastic aggregate is much lower than that of natural aggregate. The specific gravity of plastic aggregate is 0.9-1.4, which is lower than the commonly used natural aggregate. The bulk density of plastic aggregate is much lower because of the hollow sections between the plastic aggregate particles. However, the bulk density of plastic aggregates depends on the type of recycling method used on the plastic. The normal mechanical recycling method produces a low bulk density plastic aggregate, while the melting process of recycling plastics leads to a higher bulk density plastic aggregate.

With the advancement of lightweight concrete using recycled plastic waste, (Choi, Moon, Kim, & Lachemi, 2009) investigated lightweight concrete using fine aggregate from recycled polyethylene terephthalate waste bottles. The properties of concrete when waste lightweight aggregate was used as fine aggregate were examined. In comparison to control concrete, after 28 days, the compressive strength decreased by 5 %. 15 % and 30 % when polyethylene terephthalate waste bottles content increases by 25 %, 50 % and 75 %, respectively. Furthermore, for a water-binder ratio of 0.49, the concrete containing 25 % polyethylene terephthalate waste bottles showed high structural efficiency compared to the control concrete.

The physical and mechanical properties of mortar containing waste polyethylene terephthalate was investigated by (Ge, Sun, Zhang, Gao, & Li, 2013). They performed infrared spectrum teste to analyse the mechanism of strength development. Their result indicated mortar with recycled was polyethylene terephthalate showed greater strength compared to mortar with single-sized gradation. As the ratio of polyethylene terephthalate increases, the f_c' and f_f of the mortar also increased. The f_c' could reach up to 30 MPa in 3 h, about 90 % of the 7-day strength. The strength development was not influenced by the curing time. Their study introduced an innovative method of creating new mortar material by waste of polyethylene terephthalate bottles.

In an effort to understand the mechanical properties of concrete reinforced with recycled high density polyethylene plastic fibres, (Pešić et al., 2016) investigated the potential engineering advantages of applying extruded recycled high density polyethylene in concrete. They testes seven series of samples: one was made up of plain concrete, and using two fibre diameters $(\theta_1 = 0.25mm)$ and $(\theta_2 = 0.40mm)$, three specimens with 0.4 %, 0.75 % and 1.25 % volume fraction of fibres. They measured f_c', elastic modulus of concrete, f_t and flexural modulus. They observed that the f_c' and elastic modulus remain the same, the f_t and flexural modulus increased marginally between 3 % and 14 % when high density polyethylene are added. The serviceability of the concrete was improved by reducing dying shrinkage and water permeability. Using a scanning electron microscope, the ductility of the high density polyethylene fibre was analysed. Their study concluded that the use of recycled high density polyethylene fibres can create a new value chain in the construction industry including the added environmental benefits it provides.

To increase the strength of concrete structures, the study of (Chaudhary, Srivastava, & Agarwal, 2014) focused mainly on the use of waste plastic bags, that is low density polyethylene in concrete. Two mixtures was used, one with superplasticizer and one without superplasticizer. The percentage weight with plastic bags produced were 0 %, 0.4 %, 0.6 %, 0.8 % and 1.0 %. They observed a gain in f_c' and f_{st} of the concrete with low density polyethylene waste. The curing age of 7 and 28 days were tested for all the specimens.

Studies using high density polyethylene as aggregate in concrete are limited compared to other plastic waste. However some studies have its effects on strength and other properties of concrete. Concrete are made up of cement, water, fine and coarse aggregate and admixtures. The gap between coarse aggregate are filled by mortar, and the gap between fine aggregate are filled by paste. The composition of paste include cement, water, minerals, chemical admixtures which include (water reducing admixtures and viscosity modifiers) including air (Li, Chen, & Wan, 2017) as mentioned earlier, research in the area of concrete performance improvement includes replacing the fine and coarse aggregate with other minerals and plastic waste.

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2.3 High Density Polyethylene (HDPE)

HDPE is a hydrocarbon polymer manufactured from ethylene/petroleum using a catalytic process. It is a type of thermoplastic that is famous for its f_t and its outstanding property of withstanding high temperature. It can be moulded or welded together due to its high chemical resistance property.

Listed below are some of the properties of high density polyethylene (Federation, 2018):

Physical properties:

Density: 0.944 - 0.965 g/cm^3

Tensile strength: 0.20 - 0.40 N/mm^2

Thermal coefficient of expansion: 100 - 220x10^{-6}

Maximum continuous operating Temperature: 65 °C

Level of Resistance to chemicals:

Dilute acid	: HIGH
Aromatic hydrocarbons	: LOW
Dilute alkalis	: HIGH
Oils and greases	: MODERTATE
Alcohols	: HIGH

The physical and chemical properties of HDPE made it an attractive material in the construction industry including asphalt mixtures. The fatigue and rutting performance of hot asphalt mixture when HDPE is added was studied by (Moghadas Nejad, Azarhoosh, & Hamedi, 2014). To assess the impact, mixtures with and without HDPE was analysed in dry and wet conditions. Their results showed a higher fatigue life for mixtures containing HDPE, it also offers a better resistance to rutting due to its high stiffness property.

A study by (Shanmugapriya, M., & Santhi, H. (2017)) analysed the strength and chloride permeability of concrete containing HDPE waste by testing the mechanical and chloride properties when fine and coarse aggregate are partially replaced with HDPE. In their study, six different concrete mixtures of M25 grade were used. A fine aggregate partial replacement of 5, 10 and 15 % and coarse aggregate of 10, 15, and 20 % with HDPE. Compressive, splitting and flexural tests were performed to test mechanical properties, and rapid chloride penetration test (RCPT) was used to measure the chloride permeability. Figures 2.1, 2.2, and 2.3 describes the results from their experiment compared to controlled concrete (CC).

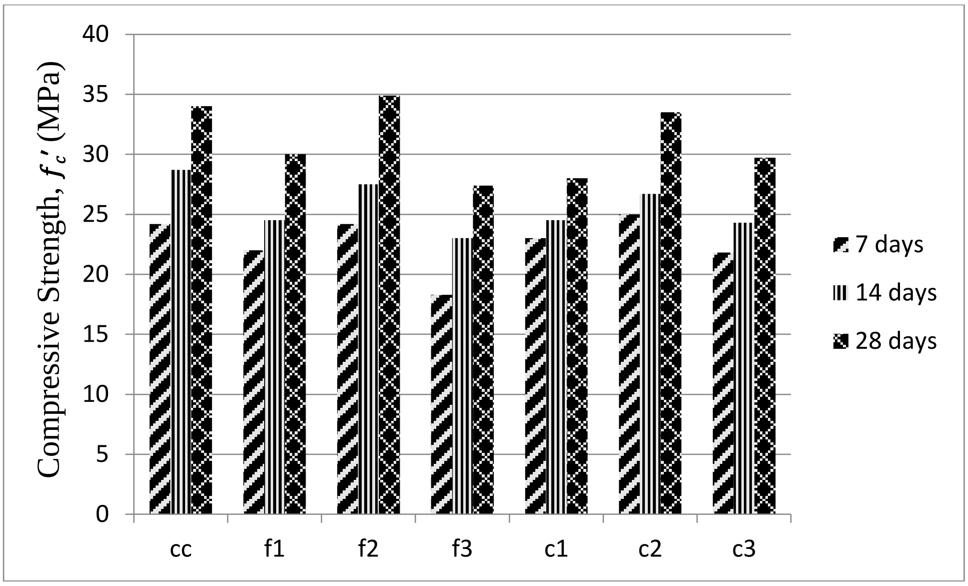


Figure 2.1: f_c' of Concrete Mixes

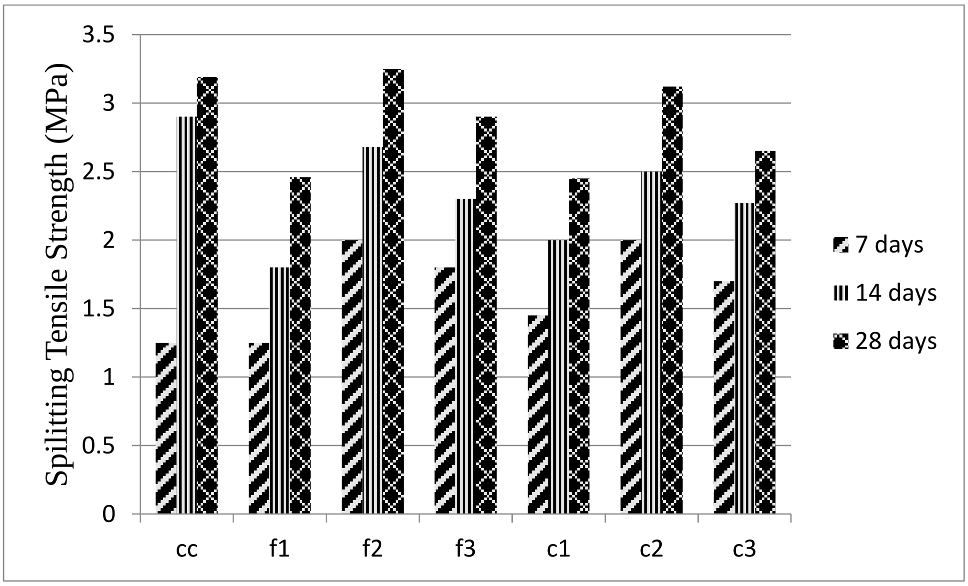


Figure 2.2: f_{st} of Concrete Mixes

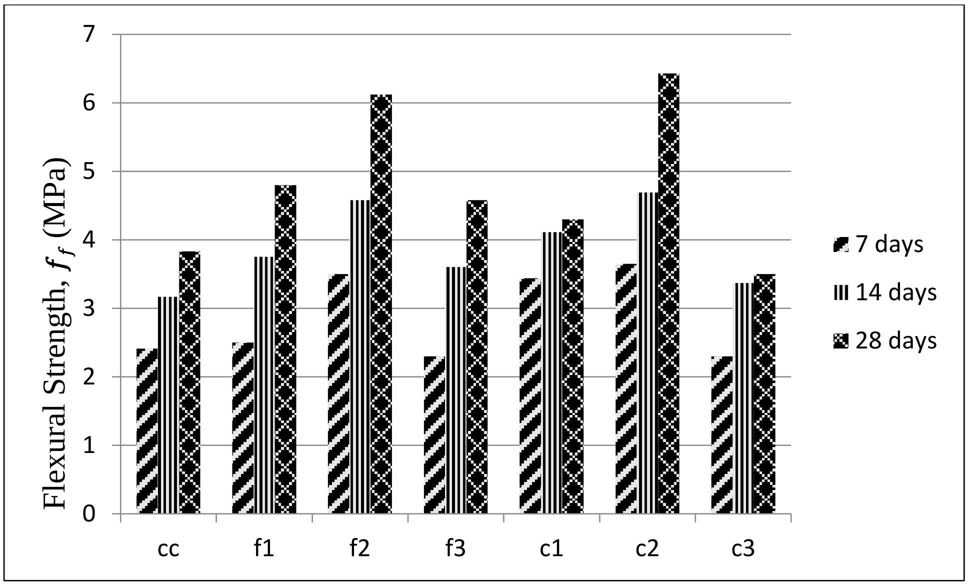


Figure 2.3: f_f of Concrete Mixes

2.4 Self-compacting Concrete (SCC)

Structural durability has been a focus of construction research for decades. Professor Okamura introduced the first SCC in the late 1980's as an attempt to improve structural durability (Okamura, 1997; Okamura & Ouchi, 2003).

In the absence of external vibration due the ability of SCC to achieve full compaction, it was considered as a high performance concrete (Okamura & Ouchi, 2003; Shi, Wu, Lv, & Wu, 2015). The three stages that define high performance concrete are as follows (Okamura & Ouchi, 2003):

- Fresh state: self-compatibility
- Early age state: avoiding initial defects
- After hardening state: protection against external aspects

The design of mixture proportioning is considered to be the major process in producing SCC. The mixture proportions affects the evaluation of the properties of the concrete obtained after production (Su, Hsu, & Chai, 2001). The fresh state of

SCC exhibits the following properties: segregation resistance, self-compacting and fluidity. Figure 2.4 shows the compares the mixture proportion of SCC and normal concrete.

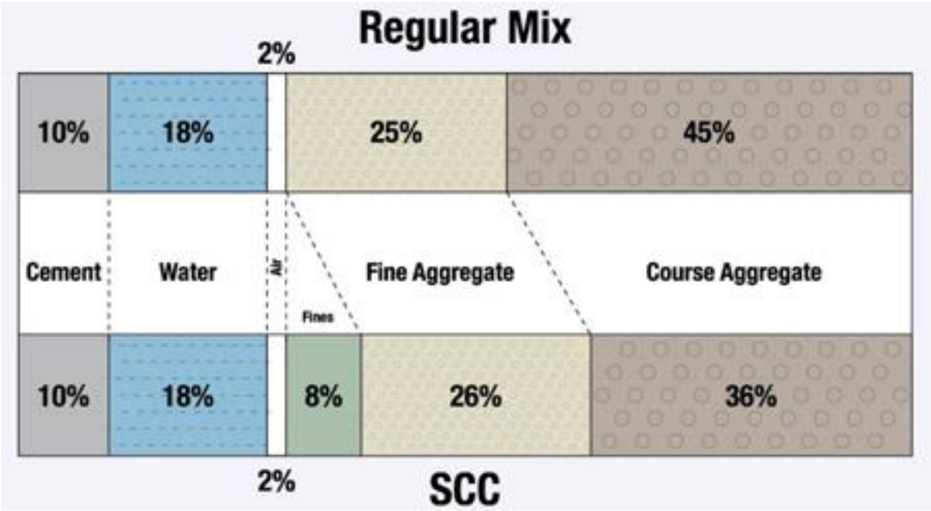


Figure 2.4: Comparison between SCC and Normal Concrete Mix Desgin (Okamura & Ouchi, 2003)

Compared to other construction materials, SCC still has a limited use despite its advantages. This is mostly due to its high self-weight (Lotfy, Hossain, & Lachemi, 2014). It is therefore logical to assume that light weight aggregate can be used in place of the conventional aggregate to reduce the self-weight of the SCC and develop a new high performance concrete. This will combine the favorable characteristics of lightweight aggregate and SCC.

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). The physical, chemical and mechanical properties of HDPE in combination with the properties of SCC may produce a durable mixture in construction.

2.4.1 Advantages of SCC

Adequately proportioned and casted SCC may lead to both economic and technological advantages in construction. The in-place cost savings and performance improvement are the motive behind the usage of SCC. Moreover, SCC will offer the following advantages (Alyousif, A. (2010)).

- Deduction in manpower and equipment can cause saving of buying and maintaining equipment, additionally, this may inspect less necessity for screeding due to the good surface finishability (self-levelling characteristics).
- Fast construction due to the high rate in casting and placing;
- Enhanced durability and reliability of concrete structures and the elimination of implicit human mistakes;
- Decreased noise levels;
- Securing a safer and healthier working environment and reducing accidents; and
- By using a proper proportioned SCC mixtures with proper handling and placing techniques will end with smooth surfaces, honeycombing free and much less bleeding.

2.5 Silica Fume (SF)

Silica fume is known to improve f_c' and reduce porosity in concrete. All of which increases the durability of concrete to produce high performance concrete. Using silica fumes in concrete mixture improves the mechanical properties of concrete (Wang & Meyer, 2012). The effects of silica fumes on high performance concrete was analyzed by (Mazloom, Ramezanianpour, & Brooks, 2004) with a W/b ratio of 0.35 and silica fume replacement levels with cement (0 %, 6 %, 10 % and 15 %).

Workability of the concrete decreased during experimentation. They observed an improvement in f_c' and secant modulus after 28 days.

2.6 Compressive Strength of Concrete (f_c')

The f_c' of a concrete represents the maximum resistance of the concrete to axial loading when a compressive resistance machine is used. The unit is pound per inch square (Psi) or Newton per millimetre square (MPa). The f_c' is usually performed at age 28 days of the concrete specimen (Kosmatka, Kerkhoff, Panarese, MacLeod, & McGrath, 2002).

f_c' is considered to be the most important mechanical characteristic of concrete. It represents the maximum load that a certain unit area of the concrete can carry. The purpose is securing quality and specifications in the construction manufactory (Gambhir, 1995; Neville & Brooks, 1987)

2.6.1 Effect of HDPE on Compressive Strength (f_c')

The study of (Badache, Benosman, Senhadji, & Mouli, 2018) using HDPE as an aggregate with percentages of 15 %, 20 %, 45 % and 60 % showed a decrease in the f_c' by 2, 6 and 10 MPa, respectively. They concluded that substituting sand with HDPE has a negative effect on the f_c'. Some studies (Hannawi, Kamali-Bernard, & Prince, 2010; Liguori, Iucolano, Capasso, Lavorgna, & Verdolotti, 2014) states that the negative effect of HDPE on f_c' is due to the low adhesion strength between the HDPE plastic and the cement paste.

2.7 Effect of HDPE on Tensile Strength (f_t)

f_t is a fundamental mechanical characteristic of concrete. It represents the maximum amount of load (tensile stress) a concrete can handle before cracking. Identifying the load under which a concrete may crack is important for structural safety and quality.

The result of f_t by (Akter et al., 2018) on concrete with and without high density polyethylene when treated with sawdust showed a 20.04Mpa for concrete with 100 % high density polyethylene, which is better than concrete without high density polyethylene composite. Their result showed an improved f_t $f_t$when high density polyethylene is combined with sawdust.

2.8 Effect of HDPE on Flexural Strength (f_f)

f_f is a measure of tensile strength of a concrete. It is referred to as the measurement of an unreinforced concrete beam or slab to resist failure during bending.

The effects of plastic aggregate such as high density polyethylene on the f_f id generally less than that of conventional concrete. Previous studies showed that the f_f can be decreased by only about 5 % at 25 % substitution level of plastic aggregates (Gu & Ozbakkaloglu, 2016). (Akçaözoğlu & Ulu, 2014) observed an almost linear decrease in f_f when there is increase in plastic aggregate in a concrete.

The study of (Badache et al., 2018) using high density polyethylene examined the f_f of the specimen after 3, 7, 28, 90 and 180 days of conservation, according to the standard EN 196-1. Their results showed a decrease in f_f. They also concluded that the higher the high density polyethylene content, the lower the f_f.

2.9 Effect of HDPE on Ultrasonic Pulse Velocity (UPV) Test

UPV tests the concrete quality. It is an in-situ concrete test that checks the quality and natural rocks of the concrete. The velocity of an ultrasonic pulse passing through the structure of the concrete (Komlos, Popovics, Nürnbergerová, Babal, & Popovics, 1996).

The study of (Badache et al., 2018) using recycled HDPE in concrete mortar analysed the ultrasonic velocity of their samples. Using the ASTM-C597-02 ultrasonic velocity test, they concluded that addition of recycled HDPE reduces the weight of the concrete which in turn affects the ultrasonic pulse velocity. The value of the ultrasonic pulse velocity decreased as the percentage containing HDPE with sand decreases.

Chapter 3

METHODOLOGY

3.1 Introduction

In this study, in order to determine the effect of the HDPE plastic as a partial replacement for coarse aggregate on both the fresh and hardened properties of SCC, six different unique mixtures were made with a w/c ratio of 0.45. The first mixture, which is normal SCC, is the control mixture. However, the other five mixtures contained HDPE as partial replacement for coarse aggregate at 5, 10, 20, 30 and 40 %. Since we couldn't achieve SCC at 40 % replacement level, it was decided to stop at 30 % replacement level of HDPE with coarse aggregate and the mixtures were tested to determine the impacts and effects of replaced HDPE on the mechanical properties of SCC. The experiments performed in this study are listed as follows:

- Fresh SCC tests: L-box, slump flow, and V-funnel tests.
- Flexural, Splitting tensile and Compressive strength tests.
- Ultrasonic pulse velocity test before and after exposure to heat at 100 and 200 °C.
- Stereo-microscope cracks examination before and after exposure to heat at 100 and 200 °C.

3.2 Material Properties

The materials used throughout the experiments are described in the succeeding parts.

3.2.1 Cement Type

Slag Portland cement CEM II/B-M (S-L) of grade 32.5 R was used in this study. This type of cement has a high resistance in its modification against direct sulphate exposure. It ordinarily has low rate of hydration and low heat generation. The physical and chemical analysis of the cement used are shown in Table 3.1.

Table 3.1: Physical and Chemical Properties of Cement

CEM II/B-M 32.5			
	Property		Oxide (%)
Chemical Analysis	IR		0.1
	LOI		10.9
	SO_3		2.2
	SiO_2		18.7
	CaO		60.4
	free CaO		1.0
	MgO		2.0
	Al_2O_3		4.0
	Fe_2O_3		2.6
Physical Analysis	SG		3000(kg/m^3)
	Fineness		4007(cm^2/g)
	90 µm Sieve Residue		0.3(%)
	45 µm Sieve Residue		5.2(%)
	w/c Ratio		28(%)
	IS Time		185(min)
	Compressive Strengths (MPa)	2 days	15.8
		7 days	29.9
		28 days	41.3

3.2.2 Mixing Water

The characteristics of water used in SCC mixture and curing procedure: alkali, contains organic materials, and acid-free.

3.2.3 Fine Aggregate (FA)

Sand less than 5 mm in size and crushed FA with a maximum size of 5 mm was used as FA in the mixtures. The ASTM C136M-14 was applied for sieve analysis to determine the gradation and it is compared with ASTM C33/C33M-16 standard limits provided in Figure 3.1.

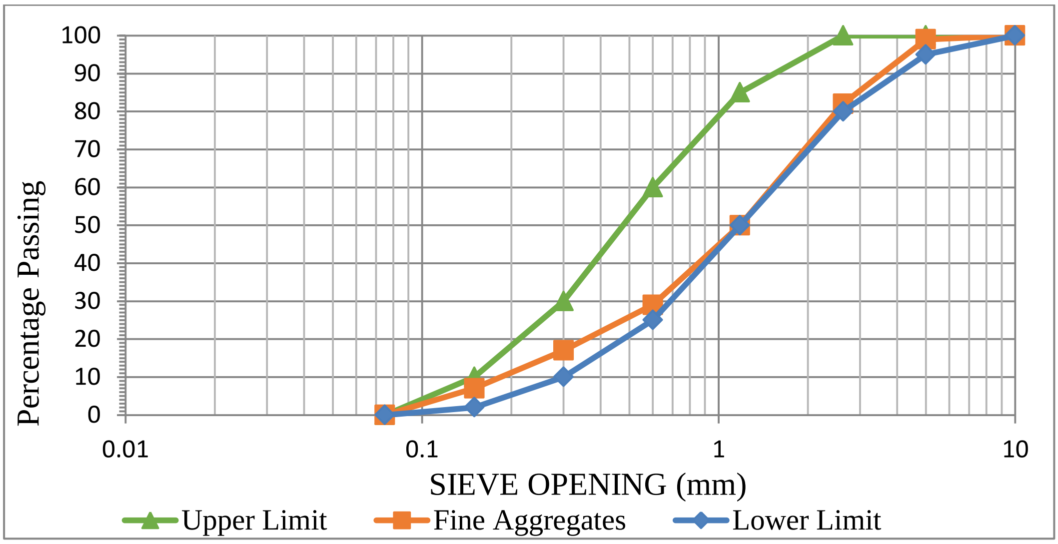


Figure 3.1: Grading Curve of FA

3.2.4 Coarse Aggregates (CA)

Following a process to determine the appropriate CA size for SCC, a maximum size of 10 mm for the CA was used in the SCC mixtures. ASTM C136M-14 standard was performed to establish the gradation of the CA as shown in Figure 3.2.

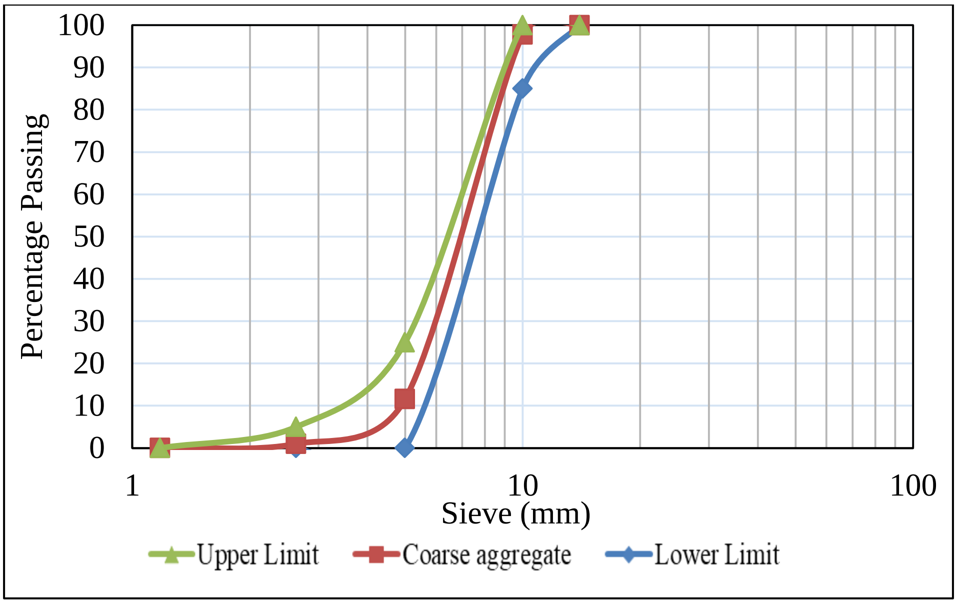


Figure 3.2: Grading Curve of CA

3.2.5 High Density Polyethylene (HDPE)

HDPE were obtained by crushing garbage plastic jars (970 kg/m^3 density) after cleaning the nylon and paper stuck on the jars. The maximum size of the HDPE was 10 mm in diameter and has been used as a replacement for the volume of course aggregate in five different percentages as 0, 5, 10, 20 and 30 %. After the plastic dried, they were crushed by a rotating crusher machine.


Figure 3.3: HDPE

3.2.6 Silica Fume (SF)

In this research, SF has been used as an addition to the mixtures in terms of cement weight in all of the mixtures. The purpose of this addition is improving the mechanical properties of SCC for long-term durability and hardness. In Table 3.2 below is a brief description of the chemical and physical properties of SF.

Table 3.2: Physical and Chemical Properties of SF

Property	Amount
SiO_2 (%)	91.0
AL_2O_3 (%)	0.58
Fe_2O_3 (%)	0.24
CaO (%)	0.71
MgO (%)	0.33
SO_3 (%)	1.84
Specific surface area (cm^2/g)	-
Particle size (µm)	96.5
Specific gravity (g/cm^3)	2.2

3.2.7 Superplasticizer

Master Glenium 27 was used in all experiments and is produced by modifying polycarboxylic ether polymer. In all the SCC mixtures, Glenium 27 was used as 1.7 % addition by the binder weight. This water reducing admixture fulfil the desire for high strength, durability, and workability desired by the ready-mixed concrete industry. It is equally a key material used in the production of SCC because of its sublime scattering impact. The lower w/b requirement does not fundamentally affect its workability maintenance, thus allowing this admixture to produce high-quality concrete mixtures.

3.3 Mixture Proportioning of SCC

The mix design is the amount and proportion calculated for each of the ingredients and materials to satisfy the mixture properties and characteristics before hardening (as workability) and after hardening (as long-term durability and strength) in orders to get the required concrete mixture. Table 3.3 below provides the mixture proportioning of SCC utilized in this study.

Table 3.3: Mixture Proportioning of SCC with 0.45 W/b Ratio

Mixture Type	HDPE (%)	Cement (kg/m^3)	HDPE (kg/m^3)	Water (kg/m^3)	FA (kg/m^3)		Coarse Aggregate (kg/m^3)	Superplasticizer (kg/m^3)	Silica Fume (kg/m^3)
					3 mm	5 mm			
SCC00HDPE	0	400	0	198	915	915	812,0	7.7	40
SCC05HDPE	10	400	14.49	198	915	915	773.2	7.7	40
SCC10HDPE	10	400	29.00	198	915	915	734.4	7.7	40
SCC20HDPE	20	400	57.90	198	915	915	658.6	7.7	40
SCC30HDPE	30	400	86.83	198	915	915	579.2	7.7	40

3.4 Experimental Program

In order to investigate the effects of HDPE partial replacement in SCC, five distinctive proportions 0, 5, 10, 20, and 30 % with w/c ratio of 0.45 integrated with silica fume and Glenium 27 were designed. After performing tests, the experimental outcomes of every sample were compared with the end result of the control mixture (0% HDPE), which was produced using only crushed coarse aggregate.

3.4.1 Mixing Process of SCC

After weighing was done, blending procedure is started by adding aggregate to each batch in a 0.25 cubic meter laboratory mixer. Next, silica fume mixed with HDPE plastics were added. After blending for 30 seconds in the mixer, water was gradually added until a homogenous paste was reached after 3 minutes of blending. In the next step, after testing the workability using the several fresh concrete tests, the concrete was placed into in the concrete mixer and mixed for a few seconds in preparation to cast SCC in molds.

3.4.2 Experiments on Fresh SCC

The goal from this experiment is to determine the effect of HDPE replacement on the characteristics of fresh SCC. The four different replacement proportions with 0.45 uniform w/b ratio were tested using three different workability tests namely slump-flow, V-funnel and L-box test.

3.4.2.1 Slump flow of SCC

According to ASTM C143/C143M 15a standard, the slump flow test is performed by filling a slump cone with HDPE SCC concrete to determine its workability, taking into consideration the requirement of SCC for this test, which is between 500-700 mm.

3.4.2.2 V-funnel – Flowability of SCC

The aim of the V-funnel test is to evaluate the time of the fresh SCC flow until the apparatus was completely empty. First, it is started by filling the apparatus totally with the fresh mixture while the trap-door is closed, then a stopwatch was adjusted before the trap-door was opened. In the next step, the stopwatch has been started immediately after the trap-door has been opened. Finally, we stop the stopwatch after the concrete is completely discharged and flow duration has been recorded. This duration should be between 6 and 12 seconds in order to maintain consistency with the property of SCC.

Figure 3.4: V-funnel

3.4.2.3 L-box Viscosity of SCC

In order to increase the precision of the test, 14 litres of fresh SCC are needed to fill the vertical side of the L-box. The device should be settled on a horizontal ground and it should be ensured that the gate opens and closes smoothly.

Firstly, we made sure that L-box was properly cleaned, dried, and closed in order to avoid excess water and draining. We then filled the vertical side of the machine with fresh SCC. In the next step, the gate was lifted to allow the mixture flow into the horizontal side of the device. When the concrete had completely streamed out to the other side, we measured its depth at 2 points: the first point, H1, is located at the beginning of the device area, while the second point, H2, is located at the end of the concrete surface in the device. Finally, we calculate the ratio of H2/H1, which should be between 0.8-1.0 to satisfy the requirements of SCC properties.

Figure 3.5: L-box Test

3.4.2.4 Casting and Curing of Test Specimens

After the fresh concrete test, the concrete mixture was put back to be mixed for a few more seconds. At this stage, different molds sizes of 150 x 150 x 150 mm cubes, 100 x 100 x 100 mm cubes,100 x 200 mm cylinders, and 100 x 100 x 500 beams were prepared to perform the hardened concrete tests as tabulated in Table 3.4.

Table 3.4: Distribution of Samples.

Test name	No. of samples	Samples shape
f_{st}	15 (3 for each HDPE percentage replacement)	Cylinder 100 x 200 mm
f_c'	15 (3 for each HDPE percentage replacement)	150 x 150 x 150 mm cubes
f_f and load deformation	15 (3 for each HDPE percentage replacement)	Beams 100 x 500 mm
Degradation and UPV	45 (9 for each HDPE percentage replacement)	100 x 100 x 100 mm cubes
f_{st} before and after heat exposure	45 (9 for each HDPE percentage replacement)	100 x 100 x 100 mm cubes
f_c' before and after two heating	45 (9 for each HDPE percentage replacement)	100 x 100 x 100 mm cubes
Microscope readings before and after degradation test	30 (6 for each HDPE percentage)	100 x 100 x 100 mm cubes
	Total = 210	

First, the molds were cleaned and oiled to avoid sticking and chemical reactions with concrete. Afterwards, the concrete was poured into the molds and stored for 24 hours in a humidity-controlled room. After 24 hours, the concrete took the shape of molds and was placed directly in a 25 ºC in a water tank for 28 days as shown in Figure 3.6 to allow it cure and harden properly in preparation for the next stage.

Figure 3.6: Water Curing Tank

3.5 Experiments on Hardened SCC

After 28 days of curing, the concrete specimens were ready to be subjected to the hardened concrete tests in order to determine the effect of replaced HDPE on hardened SCC.

3.5.1 Compressive Strength (f'_c)

After the curing stage, three cubes of size 150 x 150 x 150 mm from each percentage were taken to be tested on their f'_c according to the details of the ASTM C39/C39M – 17 standard. After testing every cube, the average was recorded to determine the effect of HDPE wastes plastic SCC on f'_c.

3.5.2 Splitting Tensile Strength (f_{st})

According to ASTM C496/C496M – 11, three cylindrical SCC specimens of size 100 x 200 mm from each percentage were cured for 28 days and prepared to be tested on their f_{st} in order to determine the effect of replaced HDPE plastic in SCC on f_{st} strength. The result was recorded by calculating the average of three cylinders for each percentage.

3.5.3 Flexural Strength (f_f)

100 x 100 x 500 mm beams were taken from the water tank after 28 days to be subjected to a FS test and connected to deformation sensor to determine their toughness and load deformation. Based on the standard ASTM C 1609, 2010, a three point loading f_f machine was loaded with a uniform 0.05 mm/ min loading rate. The loading started without any initial shock with a uniform increase in loading. The $\boldsymbol{f_f}$ was evaluated for each beam according to the maximum load before the first crack.

Figure 3.7: Flexural Strength and Toughness Test Arrangement with Yoke

3.5.4 Ultrasonic Pulse Velocity (UPV)

For this test, 100 x 100 x 100 mm cubes were taken forms the water tank after 28 curing days. A pundit test evaluates an ultra-sonic wave time travelling through a concrete specimen between two points based on the standard (BS 1881: Portion 201, 2009). This test's purpose is determining the defects present within the concrete and the f_c' of the specimen without crushing.

Figure 3.8: UPV Testing Equipment

3.5.5 Heat Exposure Tests

100 x 100 x 100 mm cubes were also used for this test. The samples were put in the oven at a uniform rate of 10 °C per minute up to 100 ºC and 200 ºC for 4 hours. After heating, they were left out of the oven to cool for six hours and another couple hours outside the oven. After the cooling stage, the samples were weighed and exposed again to the ultrasonic velocity test, then f_c' and f_{st} tests.

3.5.6 Stereo Microscope Detections

In this stage, a stereo-microscope was used to see the presence of cracks on the surface of the specimens in order to get a clear view of the effect of the high temperatures on the specimens and to compare the endurance among the three HDPE plastic percentages. Figure 3.9 shows the stereo-microscope used in this research.

Figure 3.9: Stereo-Microscope

Chapter 4

EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Introduction

This chapter explores the effects of replacing CA with HDPE plastic on the fresh and hardened properties of the five SCC mixtures produced with HDPE of five different levels 0, 5, 10, 20, and 30 %. Results and discussions are displayed for workability tests of fresh SCC, f_c' test, f_{st} test, f_f and toughness tests, ultrasonic pulse velocity (UPV) test, and degradation against heat exposure tests.

4.2 Effect of HDPE on Fresh HDPE-SCC Tests

The workability tests were performed on five different HDPE plastic replacement level mixtures at 0, 5, 10, 20, 30 % and a 0.45 w/c ratio. A superplasticizer, Glenium 27, was used in order to achieve SCC 1.7 % by mass of the cement.. Table 4.1 shows the effect of HDPE on the decrement tendency of the workability of fresh SCC.

Table 4.1: Workability Tests Records of the Five Different SCC Mixtures

	Slump Flow Test (mm)		V-Funnel Test (second)		L-Box Test (H2/H1)		
Mixture Type	Test result	Range	Test result	Range	Test result	Range	SCC requirement
SCC00HDPE	693	500-700	7.00	6-12	0.92	0.8-1	Satisfied
SCC05HDPE	690	500-700	7.50	6-12	0.90	0.8-1	Satisfied
SCC10HDPE	688	500-700	8.40	6-12	0.89	0.8-1	Satisfied
SCC20HDPE	680	500-700	8.50	6-12	0.86	0.8-1	Satisfied
SCC30HDPE	662	500-700	9.60	6-12	0.82	0.8-1	Satisfied

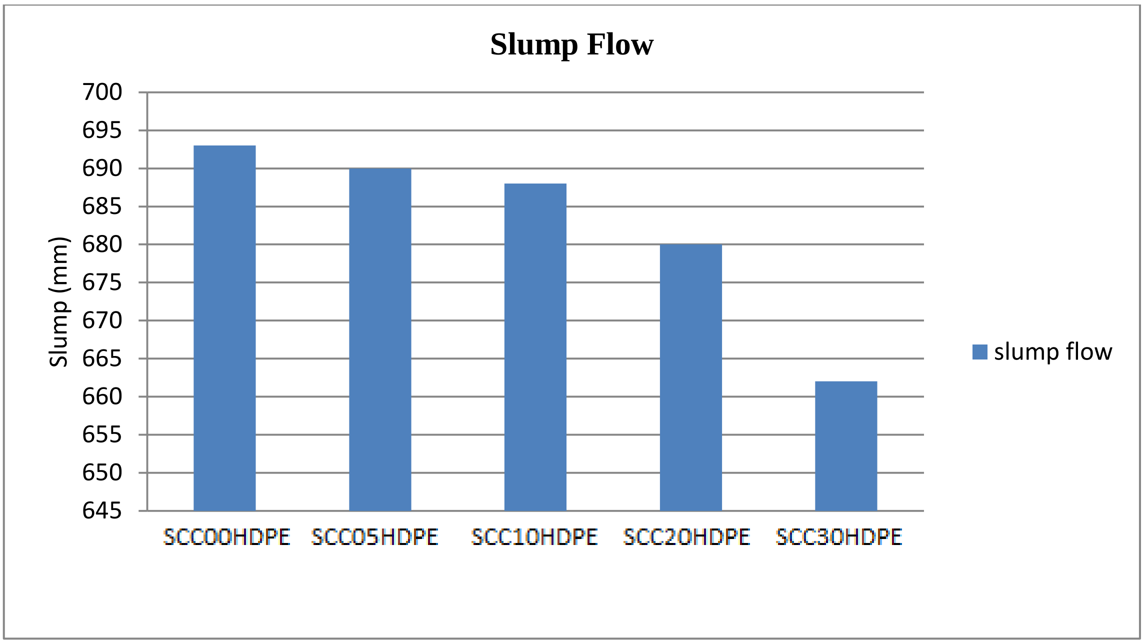


Figure 4.1: Effect of HDPE on Slump Flow

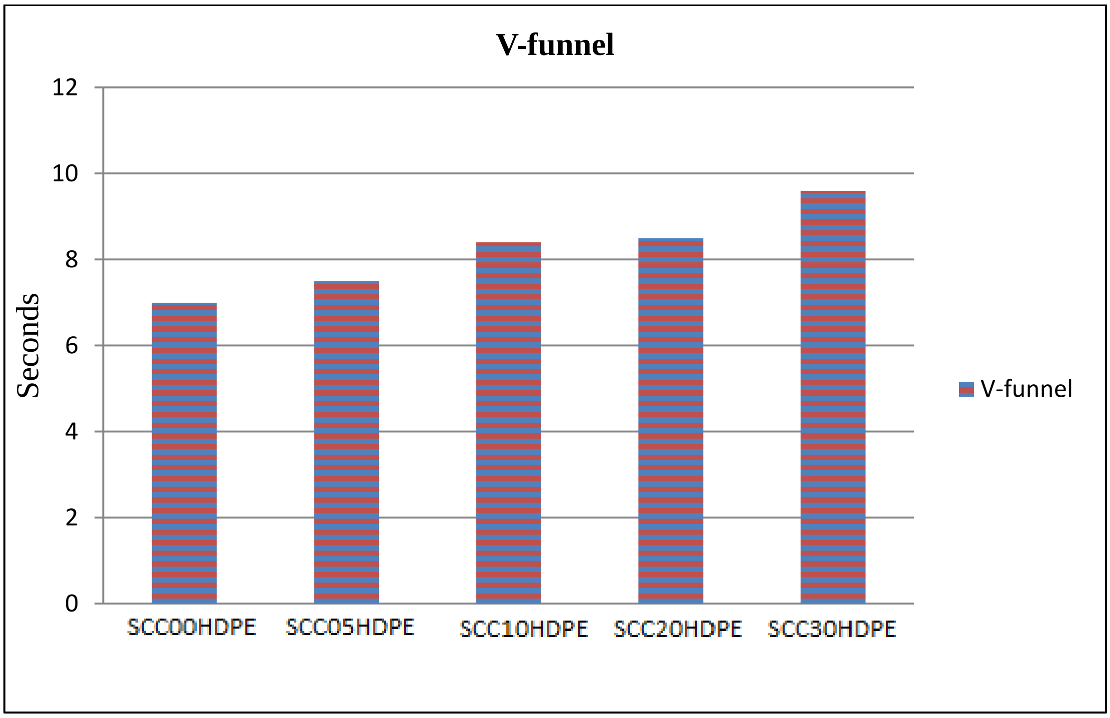


Figure 4.2: Effect of HDPE on V-funnel

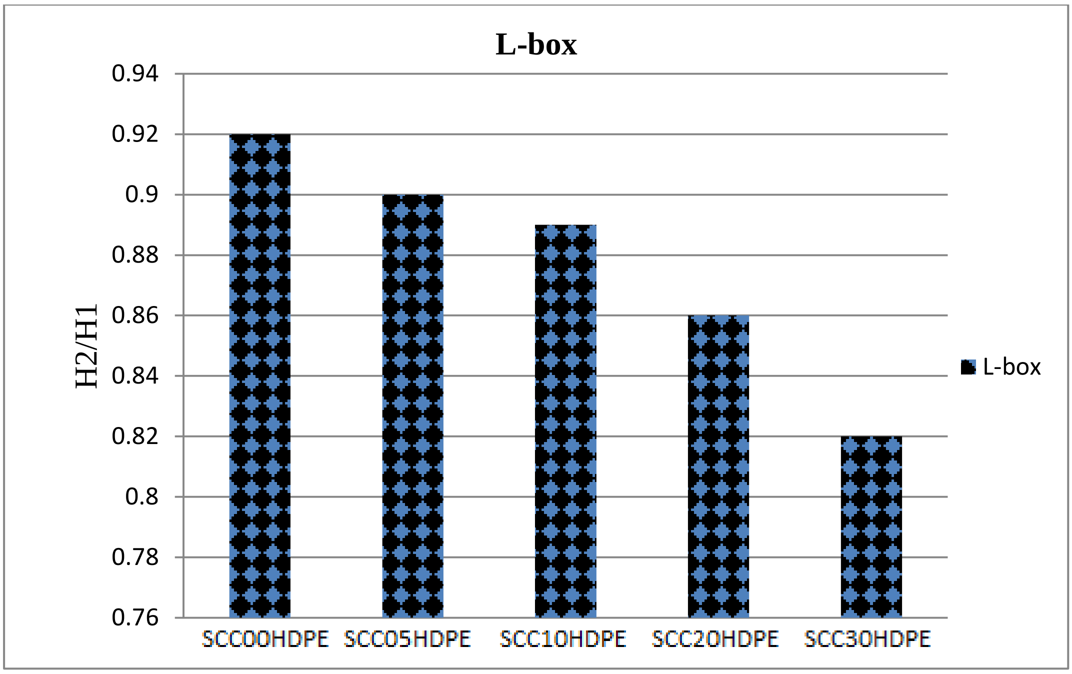


Figure 4.3: Effect of HDPE on L-box

The results of the L-Box, Slump flow, and V-funnel are drawn in Figures 4.1, 4.2, and 4.3, respectively. The results for the control SCC show satisfaction of SCC requirements in all 3 tests as shown below:

- slump flow (500-700 mm): 693 mm
- V-funnel flow (6-12 s): 7 s
- L-box (0.8-1): 0.92

For the slump flow test, Figure 4.1 clearly shows a reduction in workability proportional to increases in the amount of HDPE replaced in the mixtures to reach 690 mm, 688 mm, 680 mm, and 662 mm at 5 %, 10 %, 20 %, and 30 % HDPE substitution, respectively. These results, however, still satisfy the fresh SCC condition. Alike what (Saikia, N., & de Brito, J. (2012)) have found that the majority studies shows decrement in workability with incorporation of plastic aggregates and this decrement keep going further proportionally with increases of plastic amount in concrete mixture.

The results in Table 4.2 for the V-funnel show an increase in viscosity up to 0.23 % for 5 % HDPE replacement level relative to the control SCC to hit 9.60 s at 30 % HDPE replacement with CA in comparison to the control mixture, which demonstrates that the fresh SCC took more time to discharge from the V-funnel device after raising the amount of HDPE in the paste.

In a similar trend to what was seen in the slump flow test result, Figure 4.3 shows a reduction in H2/H1 ratio from 0.92 in SCC with 0 % HDPE to its lowest point of 0.82 at 30 % HDPE replacement level.

The decrease in workability with increases in the amount of HDPE plastic was due to the non-uniform and angular shapes of the crushed HDPE plastic particles, which were the main reason for the reduction in fluidity and increasing viscosity of the fresh concrete.

4.2.1 Relationships Among V-Funnel, L-box and Slump Flow Tests

Following the analyses carried out in the previous section, regression lines could be plotted among the different fresh concrete tests performed in order to predict the outcomes of other concrete tests. Using a Microsoft Excel 2010 plus worksheet, we outlined the linear relationships between the three previously performed fresh concrete tests, which are illustrated in Figures 4.4, 4.5, and 4.6. Figure 4.5 illustrates the proportional linear relationship between the L-box and slump flow tests due to the reductions in both tests results with increments in the HDPE replacement percentage. Conversely, the relationship between L-box, V-funnel, and slump flow are not proportional due to the increases in V-funnel results with increments in the amount of HDPE. According to Table 4.2, the highest R^2 = 0.96 is the best relationship, which is the L-box, slump flow relationship.

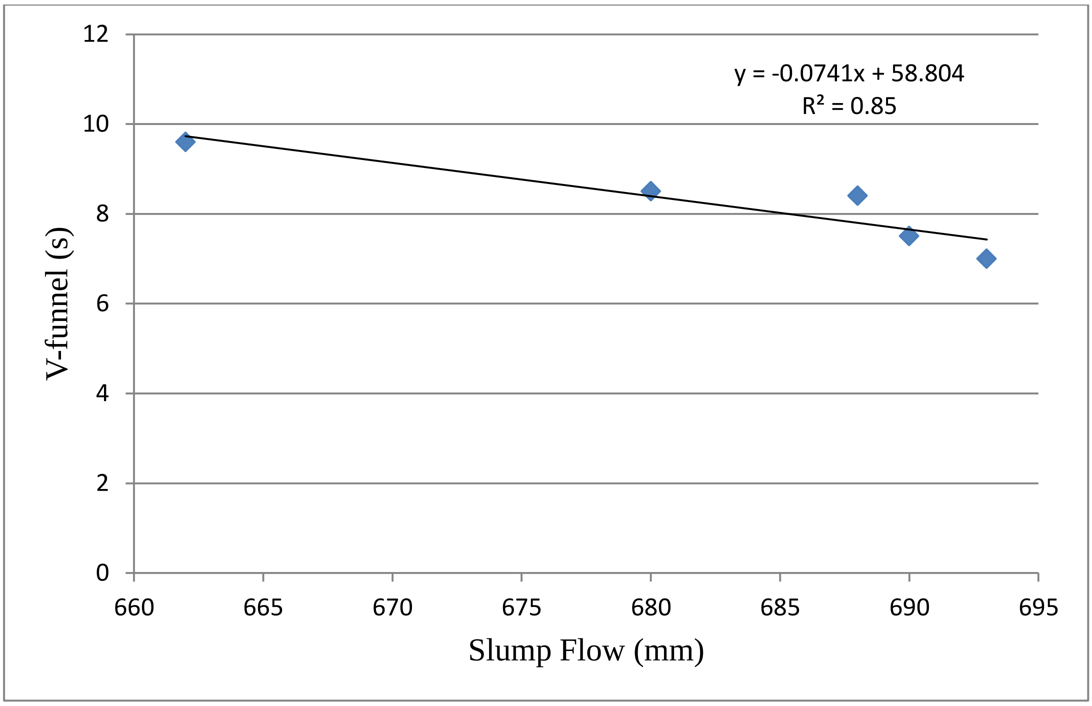


Figure 4.4: Relationhip between Slump Flow and V-funnel Tests

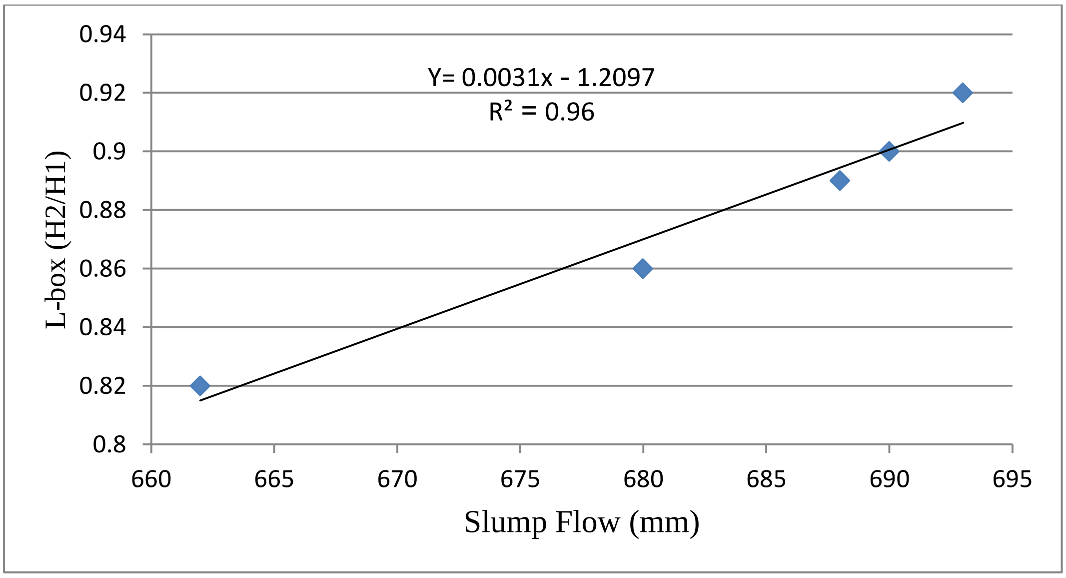


Figure 4.5: Relationship between Slump Flow and L-box

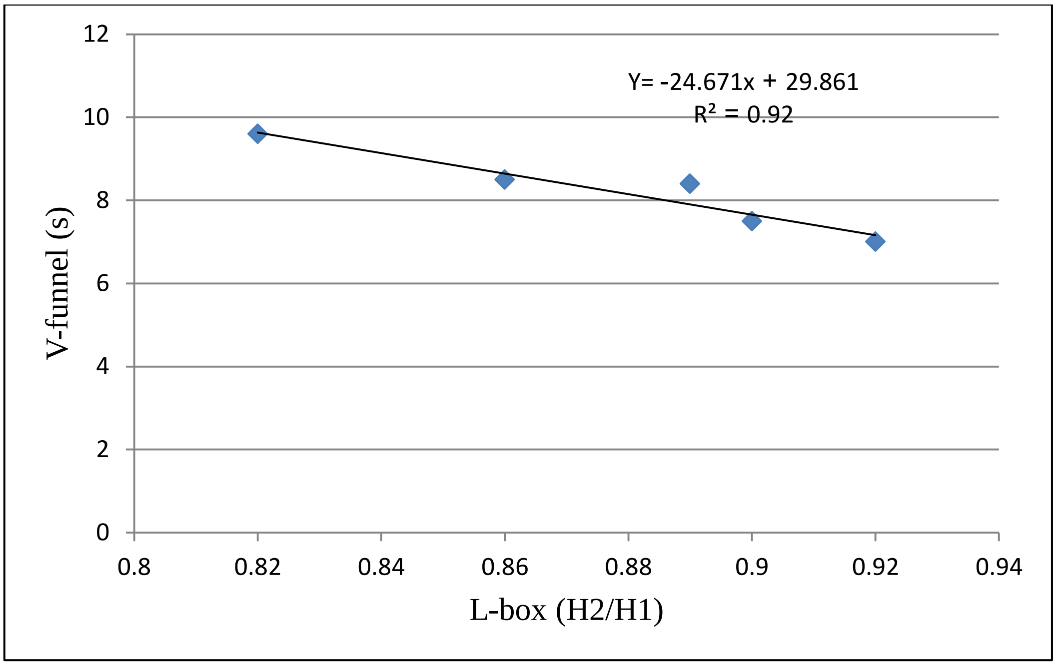


Figure 4.6: Relationship between L-box and V-funnel

Table 4.2: Linear Relationship among the Three Different Types of Fresh SCC Tests

Relationship Type	Regression Type	Equation	R^2
V-funnel - Slump Flow	Linear	Y = -0.0741x + 58.804	0.85
L-Box - Slump Flow	Linear	Y = 0.0031x - 1.2097	0.96
V-funnel – L-Box	Linear	Y=-24.671x + 29.861	0.92

4.3 Effects of HDPE on f_c' of SCC

The f_c' results for the five different mixtures after at age of 28 days are illustrated in Table 4.3 and Figure 4.7. Results show a reduction in f_c' corresponding to the percentage of HDPE plastic replacement; this reduction is beyond 27 % in comparison to the control mixture. For 5 % aggregate replacement, records show an 8.92 % reduction in f_c'compared to the control mixture (0 % HDPE). For 10 %, 20 %

and 30 % HDPE substitution, Figure 4.7 shows reductions in f_c' of up to 15.53 %, 20.15 %, and 26.64 %, respectively, relative to the control SCC mixture.

Table 4.3: Effect of HDPE replacement Levels on f_c' after 28 Days.

Mixture Type	f_c' (MPa)	Reduction in f_c' (%)
SCC00HDPE	59.63	-
SCC05HDPE	54.31	-8.92
SCC10HDPE	50.37	-15.53
SCC20HDPE	47.61	-20.15
SCC30HDPE	43.74	-26.64

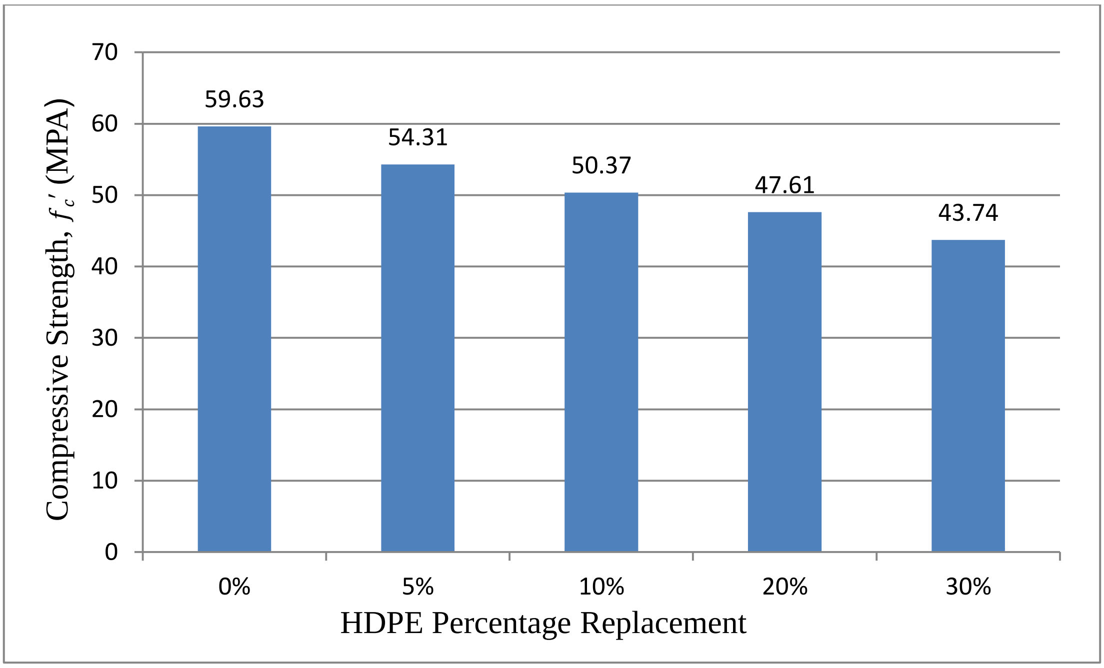


Figure 4.7: Effects of HDPE Replacement Levels on 28 Days f_c'

The reduction in f_c' is attributed to several reasons. The main reason responsible for this reduction, however, is the low bond strength of HDPE plastic between the plastic and mixture, an important factor in f_c' reduction. Furthermore, HDPE plastic is a hydrophobic material. This natural property of the plastic restrains water movement, which inhibits the hydration reaction of concrete, and causes some initial defects since HDPE cannot absorb water, as well as internal bleeding. Another property of HDPE plastic which also results in f_c' decrement is the low elastic modulus of HDPE plastic compared to normal aggregate. According to (Manjunath, B. A. (2016)), f_c' tend to decrease with incorporation with waste plastic; it is attributed to the decrement in adhesive strength among the materials since waste plastic is hydrophobic materials which lead to restrict the hydration process.

4.4 Effects of HDPE on f_{st}

The f_{st} test results of five SCC mixtures, after 28 days of curing in water tank, are shown in Figure 4.8 and Table 4.4 below.

Table 4.4: Effects of HDPE Replacement Levels on f_{st} after 28 Days

Mixture Type	f_{st} (MPa)	Load (KN)	Reduction in f_{st} (%)
SCC00HDPE	4.995	157.10	-
SCC05HDPE	4.732	148.82	-5.26 %
SCC10HDPE	4.415	138.85	-11.61 %
SCC20HDPE	4.094	128.76	-18.03 %
SCC30HDPE	3.716	116.80	-25.60 %

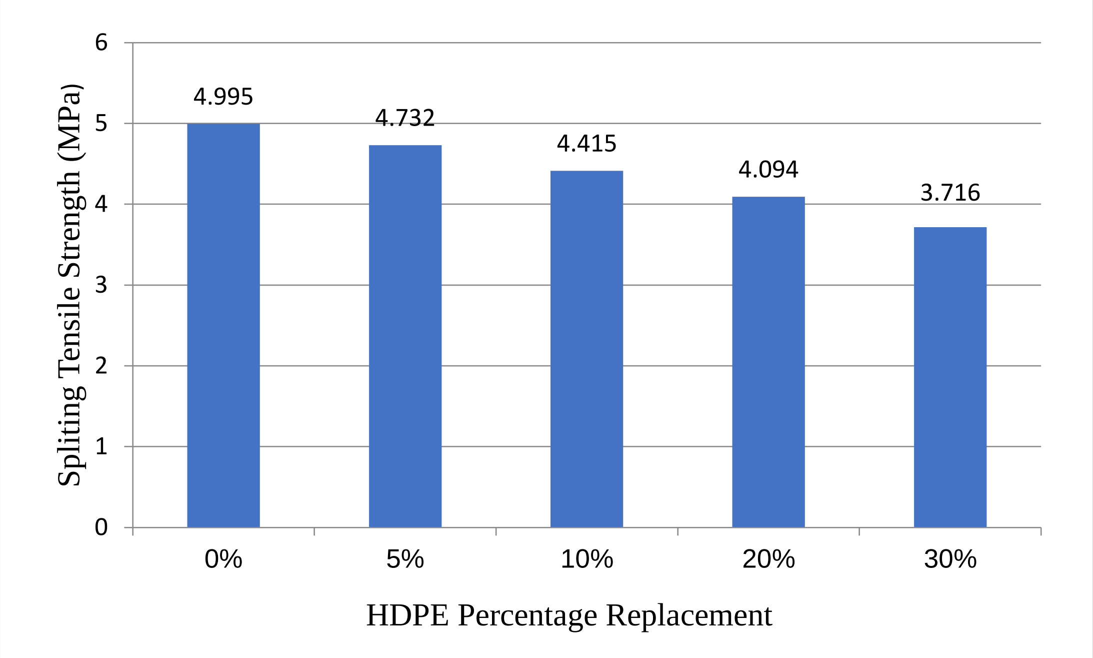


Figure 4.8: Effects of HDPE Replacement Levels on f_{st}

According to the results in Table 4.3 and Figure 4.2 above, we can clearly conclude that HDPE substitution causes a reduction in f_{st} as well. f_{st} decreases proportionally with increases in the amount of HDPE in concrete. The lowest decrement (5.26 %) unsurprisingly corresponds to the mixture with the lowest HDPE percentage (5 %). This decrement subsequently increased to reach 5.26 %, 11.61 %, 18.03 %, and 25.60 % for SCC with 10 % HDPE, 20 % HDPE, and 30 % HDPE, respectively.

The reduction in f_{st} after 28 days can be attributed to several reasons. In this study, this reduction in f_{st} is strongly related to the weakness of the bond strength between aggregates and cement paste. Moreover, by increasing the HDPE amount in the mixtures, the bond strength and ITZ (interfacial transition zone) structure between the aggregate and cement paste is mitigated by increasing water and decreasing the cement particles in ITZ due to the non-absorbent property of the HDPE plastic. In the same trend of this study, (Saikia, N., & De Brito, J. (2012)) mentioned that using any type of plastic would lower f_{st} . (Albano et al.) Concluded that the decrement in f_{st}

was due to the porosity increasing with incorporation of PET aggregate as well as increasing in w/c ratio

4.5 Relationship between f'_c and f_{st}

In the previous sections, it can be seen that when f'_c decreases f_{st} also decreases. A linear relationship between f'_c and f_{st} in the form of Y = 0.0816x + 0.2185 (R^2 = 0.97) was obtained. The linear relationship is shown in Figure 4.9. Although the best regression is polynomial R^2 = 0.99, the linear relation was chosen for simplicity.

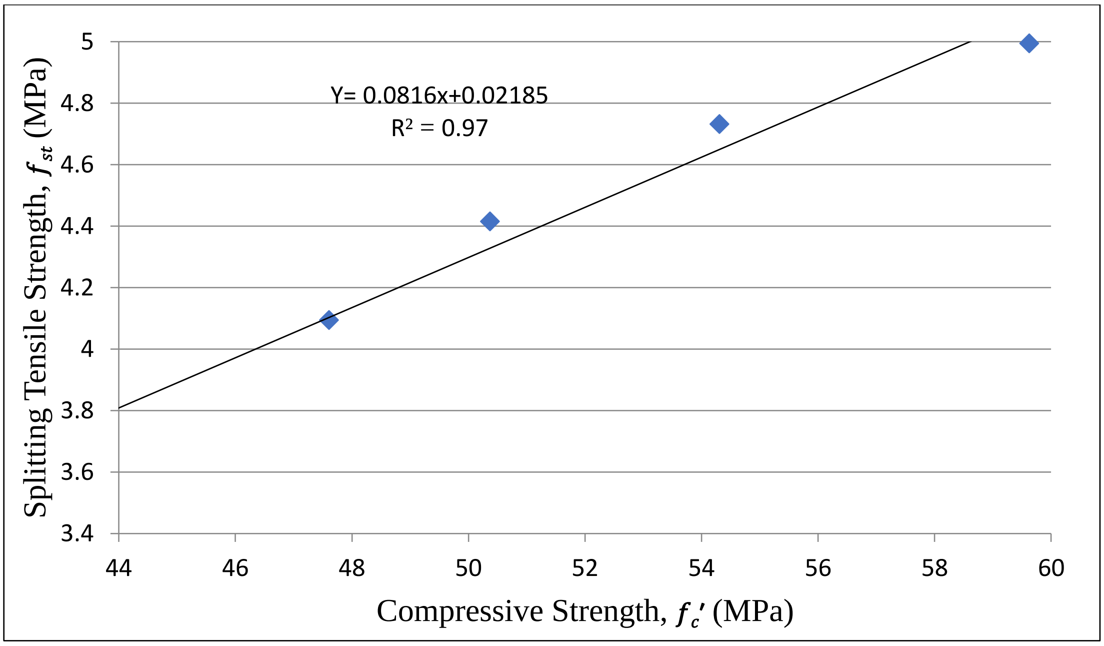


Figure 4.9: Relationship between f'_c and f_{st}

Table 4.5: Different Relationship Types between f_c' and f_{st}

Regression type	Equation	Correlation Coefficient, R^2
Exponential	$Y = 1.6753e^{0.0187x}$	0.96
Linear	$Y= 0.0816x+0.2185$	0.97
Logarithmic	$Y = 4.2181\ln(x) - 12.181$	0.98
Polynomial	$Y = -0.0026x^2 + 0.3485x - 6.6161$	0.99
Power	$Y = 0.0964x^{0.9706}$	0.97

4.6 Effects of HDPE on f_f and Toughness

The results of these tests are recorded and tabulated in Figure 4.10 and Table 4.6. They clearly show the highest f_f as belonging to the control sample in comparison to the other percentages of aggregate replacement with HDPE.

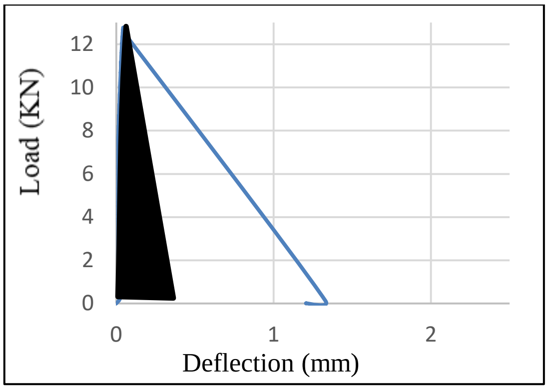
According to test results, we can see a slight reduction in f_f by 3.51 % for 5 % HDPE replacement in the mixture to 11.090 MPa. When the amount of HDPE plastic increases in the mixture to 10 %, f_f decreases by 7.44 % relative to the control sample to reach 10.638 MPa and keeps decreasing at 20 % replacement level by 12.30 % reduction to hit the lowest f_f value of 9.657 at 30 %.

We can conclude from these results that f_f decreases with increases in the proportion of HDPE replacement. The reduction in f_f results can be attributed to the accumulation of plastic aggregates which is lead to strength loss.

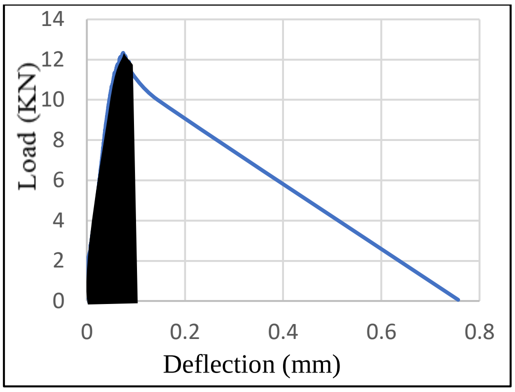
On the other hand, Figure 4.10 shows improving in ductility of the specimens corresponding to increases in the amount of HDPE in SCC mixtures. Increasing of ductility can be seen from the marked areas under the curves (see Figure 10 (a), (b), (c), (d), and (e). Meliorating in ductility of HDPE-SCC matrices can be attributed to the ability of polyethylene to stretch under stress. (Batayneh M, Marie I, Ibrahim A.) also found that incorporation of waste plastics decreases f_f; however, (Pešić et al., 2016) mentioned that using recycled HDPE fibres strengthen the bond matrix which lead to an increasing in f_f.

Table 4.6: f_f Test Results:

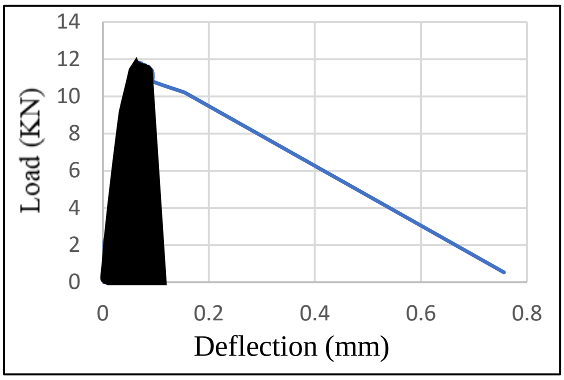
Type of Mixture	Load (KN)	f_f (MPa)	Percent Loss of f_f (%)
SCC00HDPE	12.77	11.493	-
SCC05HDPE	12.33	11.090	-3.51
SCC10HDPE	11.82	10.638	-7.44
SCC20HDPE	11.21	10.080	-12.30
SCC30HDPE	10.73	9.657	-16.00



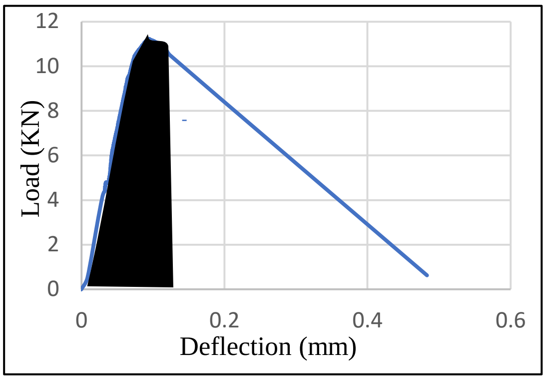
(a) Control Mixture, 0 % HDPE



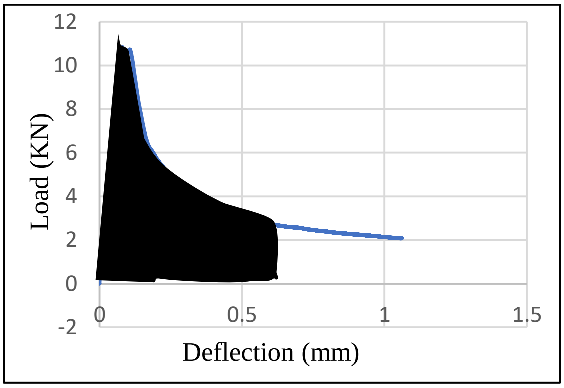
(b) 5 % HDPE



(c) 10 % HDPE



(d) 20 % HDPE



(e) 30 % HDPE

Figure 4.10: Flexural Toughness Charts for Different Proportion of HDPE Replacement levels

4.7 Relationship between f_f and f'_c

A general evaluation of the tests outlined above reveals a relationship between the f_f and f_c' of concrete. Figure 4.11 .provides a correlation intended to calculate f_c' in function of f_f. The resulting linear equations take the form of y = 0.1195x+4.481 and correlation coefficient R^2 = 0.97. The relationship between the f_f and f_c' of SCC with HDPE is proportional as it is shown in Figure 4.11, which means that f_f decreases as the f_c' of SCC decreases and vice versa.

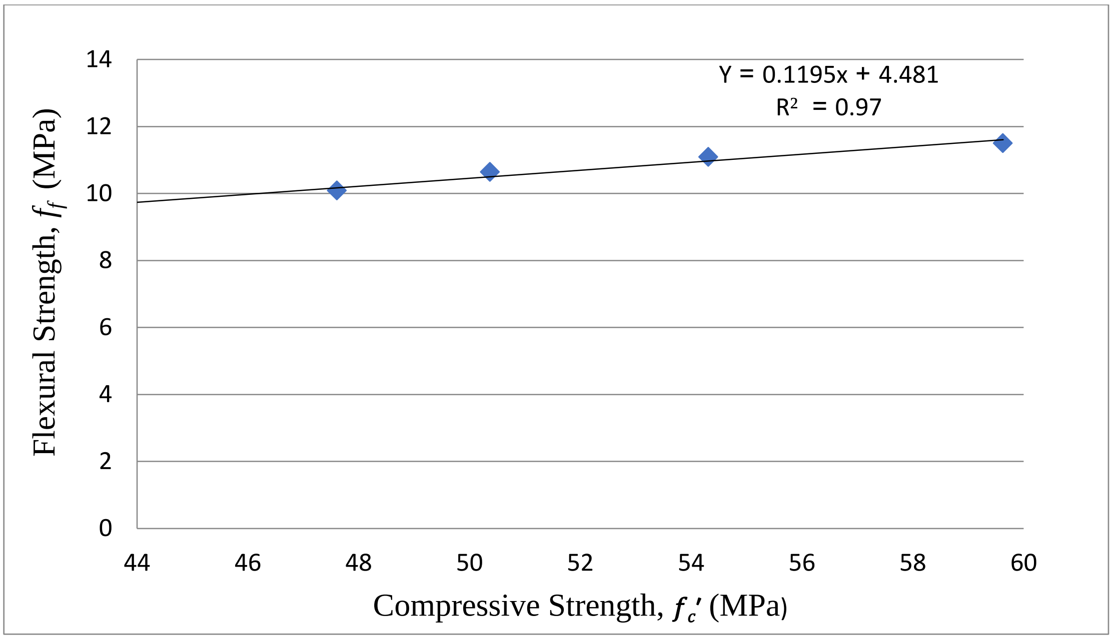


Figure 4.11: Relationship between f_f and f_c'

4.8 Effect of HDPE on Degradation of SCC by Heating

In this section, 3 cubes (100 x 100 x 100 mm) from each HDPE substitution percentage were tested for f_{st}, f_c', weight and UPV before and after heat exposure.

4.8.1 Effects of HDPE on Weight of SCC Specimens upon Heat Exposure

The purpose of this test is to determine the mass of the SCC samples for the 5 different proportions of HDPE (0, 5, 10, 20, and 30 %) before and after being heated in an oven at 100 and 200 ºC after curing for 28 days. From Table 4.7, it can be seen that there was a reduction in all of the samples after being heated. At 0 % HDPE replacement level, the mass of the cube decreased from 2.343 kg prior being heated to 2.327 kg and 2.16 kg after being heated at 100 and 200 ºC, respectively. For 5 % HDPE replacement, the weight was 2.319 kg before heating and reached 2.278 kg and 2.11 kg at 100 and 200 ºC, respectively. Table 4.7 clearly shows that the weight of the samples keeps decreasing with increases in the amount of HDPE replacement level and the heating temperature. As such, at 10 % HDPE, the weight decreases to 2.278 kg at 100 ºC and 2.11 kg at 200 ºC from an initial weight of 2.319 kg before being heated. Finally, for the 20 and 30 % HDPE substitutions, the weight of the samples before heating were 2.21 kg and 2.175 kg, respectively, which decreased to 2.13 and 2.126 kg and 2.062 and 2.047 kg at 100 and 200 ºC, respectively.

In addition to reducing the general specimens weight, the replacement of normal crushed aggregate with HDPE aggregate which has lower density also led to further decreases weight because of the evaporation of water from specimen as a result of the rise in temperature.

Table 4.7: Effect of Heat Exposure on Weight of Samples.

Concrete Mixture	Mass before heating (Kg)	Mass after heating at 100 ºC (Kg)	Mass after heating at 200 ºC (Kg)
SCC00HDPE	2.343	2.327	2.16
SCC05HDPE	2.319	2.278	2.11
SCC10HDPE	2.289	2.234	2.089
SCC20HDPE	2.21	2.13	2.062
SCC30HDPE	2.175	2.126	2.047

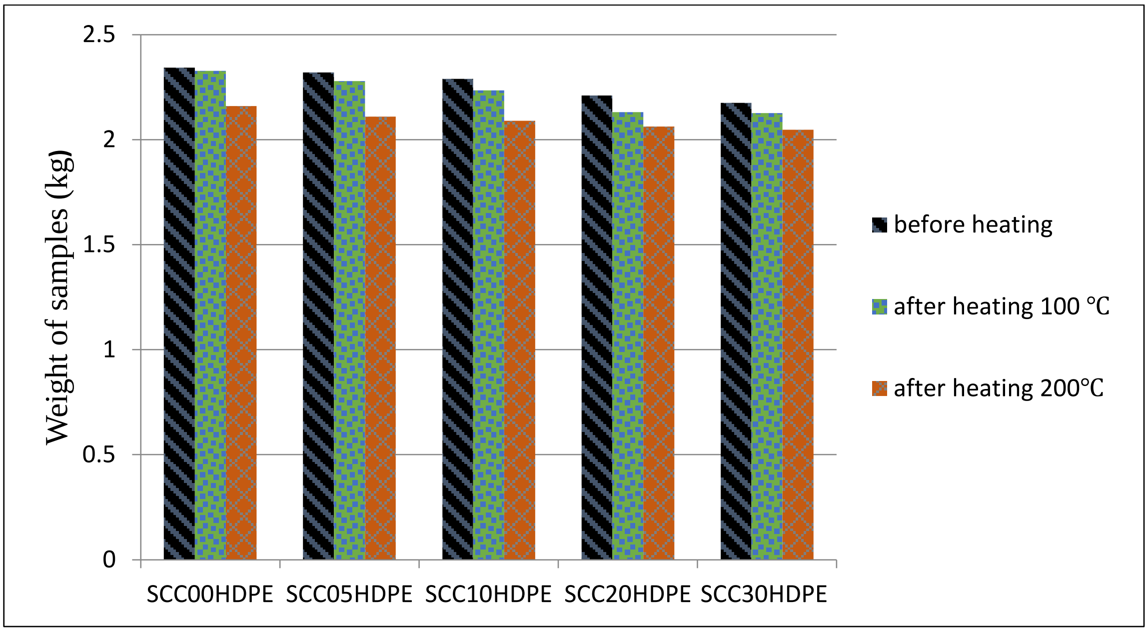


Figure 4.12: Effect of Heat Exposure on the Weight of Test Specimens

4.8.2 Effect of HDPE on UPV before and after Heat Exposure

UPV methods are aimed to draw and classify cracks, voids, and other damage in concrete, ceramics, wood, and stone by transmitting a sonic wave through the sample. Table 4.8 represent the time for the sonic wave to pass through the concrete in micro seconds. Velocity is calculated by dividing the length of the cube by the time it takes for the sonic wave to pass through (v (km/s) = D (km)/T(s)).

After applying the formula above to the results in Table 4.8, we obtained the coefficients of velocity shown in Figure 4.14. According to the results in Figure 4.14, 4.82 Km/s was obtained at for control samples (0 %HDPE). Then, the velocity decreased at 5 % HDPE replacement level to 4.5 Km/s. the decrement in velocity continued with increasing of HDPE content to become 4.14 km/s, 3.92 km/s, 3.75 km/s, at 10, 20 ,and 30 % replacement levels respectively.

Voids are created in concrete mass due to moisture evaporation during exposure of concrete to high temperature (Hassan, S. A. (2007)).When the concrete samples were exposed to elevated temperatures; this resulted in a reduction in UPV readings corresponding to the increase in temperature. The velocity was reduced from 4.82 to 4.5 Km/s at 100 ºC heat exposure and continued to decrease until it reached 4 Km/s at 200 ºC as shown in Figure 4.14

In addition, at 5 % replacement, the UPV diminishes after heating to reach 4.22 km/s at 100 ºC, and 3.66 at 200 ºC. The velocity at 10% HDPE substitution diminishes 4.4 Km/s before heat exposure to reach 4.14 Km/s at 100 ºC and 3.43 Km/s 200 ºC. By the test results, it’s clearly seen that the velocity decreased at the two heating as HDPE replacement level increased. The velocity reduction is attributed to the combination of cracks on the surface in specimens which contained HDPE aggregate (see figure 4.13), water loss, and microstructure variations in the paste upon heating, which leads to the decomposition of chemicals. The fact that the wave also has to pass through different kinds of materials (cement, normal aggregate, HDPE plastic) also negatively affects the velocity.

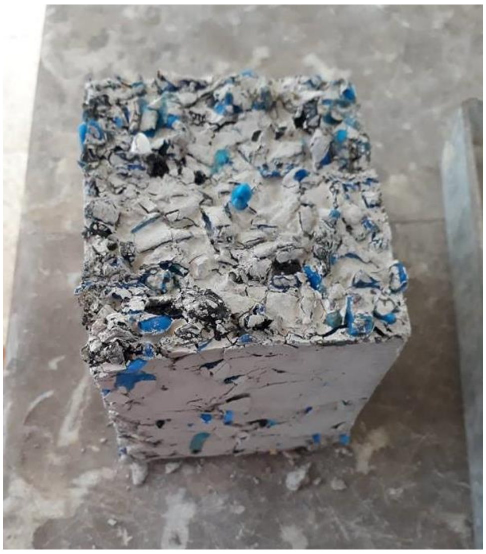


Figure 4.13: SCC30HDPE after Heat Exposure at 200 ºC

Table 4.8: UPV before and after Heat Exposure at 100 and 200 ºC.

Concrete Mixture	Time before heating (µs)	Time after heating at 100 ºC (µs)	Time after heating at 200 ºC (µs)
SCC00HDPE	20.75	22.22	25
SCC05HDPE	21	23.65	27.31
SCC10HDPE	21.7	24.15	29.14
SCC20HDPE	21.9	25.47	32.64
SCC30HDPE	22.2	26.72	35.13

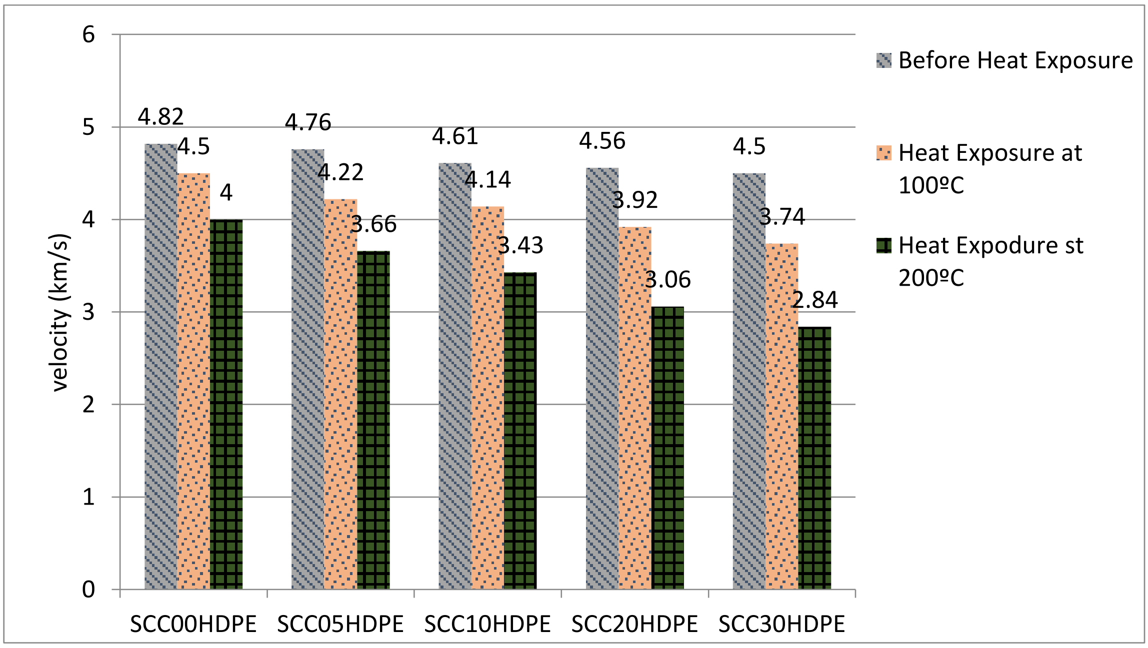


Figure 4.14: UPV before and after Heat Exposure.

4.8.3 Effect of Heat Exposure and Different Proportion of HDPE on f_c'

Table 4.9 shows the f_c' test results before and after heating at 100 and 200 ºC for small cubes 100 × 100 × 100 mm containing six different percentages of plastic replacement. The f_c' of the specimen at 0 % replacement was 70.3 MPa, and it reduced to reach 67.3 MPa at the 1st heating 100 ºC and 61.3 MPa at the 2nd heating 200 ºC. The f_c' of 5 % WHDP replacement sample before heating was 66.4 MPa and decreased to 60.02 and 54.36 MPa after heating at 100 and 200 ºC, respectively. It is evident from the foregoing that the replacement of aggregate with HDPE and temperature heating negatively affects the f_c' of concrete. Each increase in the percentage of aggregate replacement and temperature exerts a greater influence on the f_c' of the concrete (see Figure 4.15).

The first heating (100 ºC) has a lesser effect on the f_c' than the second heating (200 ºC), which shows that the evaporation of water from the concrete and the resulting cracks significantly affects f_c'

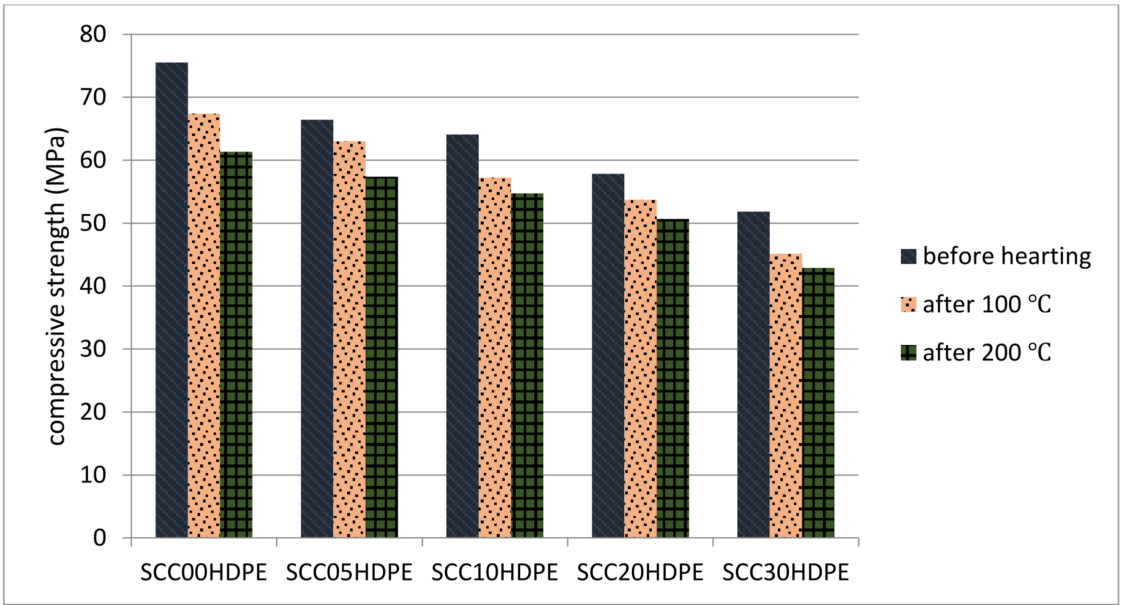


Figure 4.15: f_c' Test Result before and after Heat Exposure at 100 and 200 ºC

Table 4.9: f_c' Test Result before and after Heat Exposure at 100 and 200 ºC.

Mixture Type	f_c' before heating (MPa)	f_c' after heating at 100 ºC (MPa)	f_c' after heating at 200 ºC (MPa)
SCC00HDPE	70.3	67.35	61.30
SCC05HDPE	66.4	60.02	54.36
SCC10HDPE	61.07	55.20	52.70
SCC20HDPE	54.79	50.71	46.65
SCC30HDPE	49.83	45.09	42.89

4.8.4 Effect of Heat Exposure on f_{st}

Table 4.11 shows the f_{st} as a function of different proportions of HDPE replacement and different temperatures (before and after heating at 100 and 200 ºC) after curing for 28 days.

(Obeed, A. T. (2007)) indicate that the f_{st} decreased upon exposure to high temperatures. Furthermore, the values of the f_{st} for the concrete mixtures after 28 days of curing relative to those of the control mixture are shown in Table 4.10 and Figure 4.16. f_{st} of the control mixture was 4.339 MPa before heating and decreased to 4.255 MPa and 3.79 MPa after heating at 100 and 200 ºC, respectively.

Compared to the control mixture, f_{st} strength of the 5 % HDPE replacement mixture declined from 4.17 MPa before heating, to 3.69 and 3.42 MPa after heating at 100 and 200 ºC, respectively. The strength of the 10 % HDPE mixture was 3.68MPa before heating, which reduced to 3.21 MPa and 2.76 MPa after heating at 100 and 200 ºC. At 20 % replacement, the 3.25 MPa strength before heating declined to 3.72 MPa and 3.14 MPa after heating at 100 and 200 ºC. Similarly, before heating, the 3.07 MPa strength of the 30 % mixture reduced to 2.33 MPa after heating at 100 ºC and 2.07 MPa at 200 ºC.

Overall, heating and HDPE replacement seem to have a negative effect on the f_{st} of concrete, similar tof_c'.

Table 4.10: f_{st} Test Results before and after Heat Exposure at 100 and 200 ºC.

Concrete Mixture	f_{st} before heating (MPa)	f_{st} After heating at 100 ºC (MPa)	f_{st} After heating at 200 ºC (MPa)
SCC00HDPE	4.43	4.26	3.79
SCC05HDPE	4.17	3.69	3.42
SCC10HDPE	3.68	3.21	2.76
SCC20HDPE	3.25	2.72	2.14
SCC30HDPE	3.07	2.33	2.07

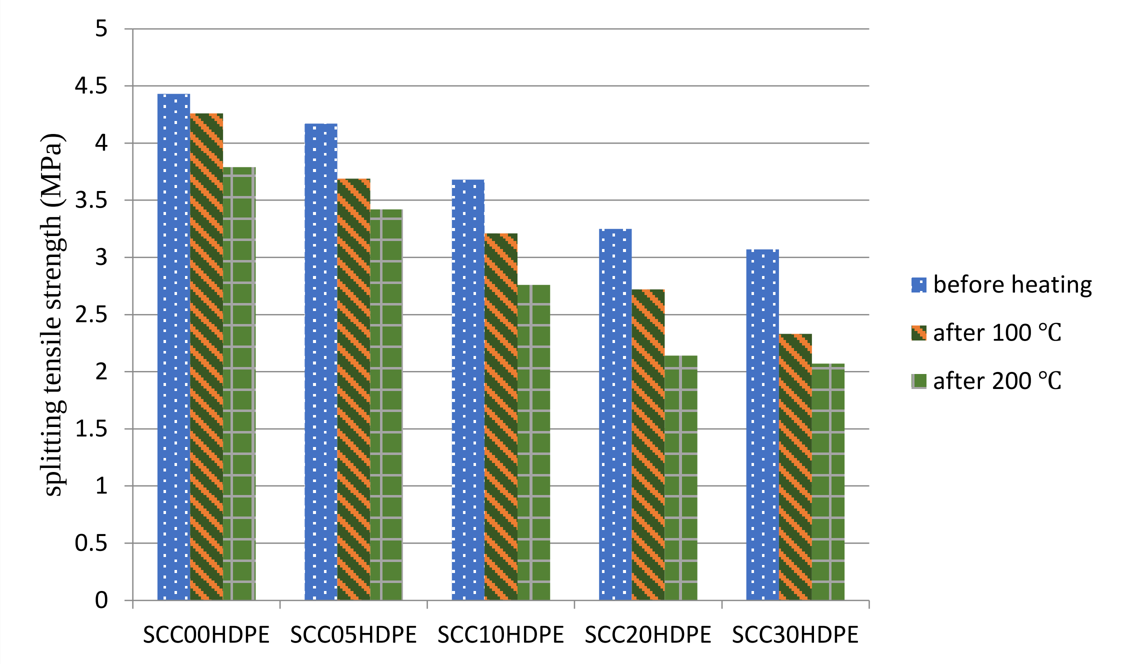


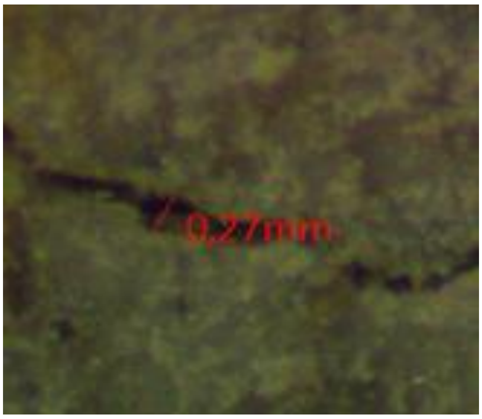
Figure 4.16: f_{st} Test Result before and after Heat Exposure.

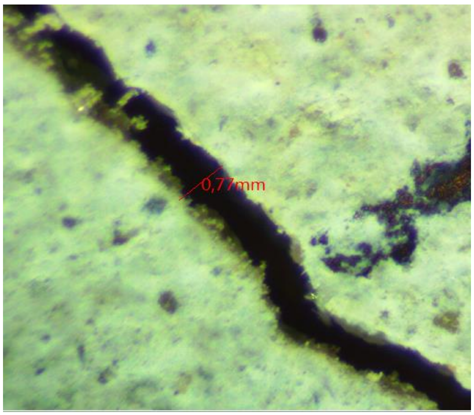
4.8.5 Microscope Observations after Heat Exposure

After their exposure to heat, the specimens began to suffer from cracks due to the evaporation of water and melted plastic within the concrete. The increase in the interior stress of the concrete changed the form of the specimen, which in turn led to cracks. The cracks visibly appeared on the specimens during the tests following increases in temperature to 100 and 200 ºC (see Figure 4.17 and Figure 4.18). The cracking became even more extreme with the increased moisture loss at 200 ºC respect of both size and number of cracks compared to the specimens exposed at 100 ºC. The width of cracks also enlarged with increase in the percentage of HDPE and temperature due to defection of plastic fraction after heating, thus illustrating the relationship between temperature, HDPE content, and cracks. The width of the cracks in the specimen increased to 1.05 mm at 30 % HDPE from 0.27 mm at 5 % HDPE at 100 ºC heating, and increased even further after heating at 200 ºC to 0.42 mm and 2.25 mm at 5 % and 30 % HDPE, respectively (see Table 4.11). The control mixture specimens did no display any surface cracks after heating at 100 ºC.

Table 4.11: Microscope Readings after Heating Exposure at 100 and 200 ºC.

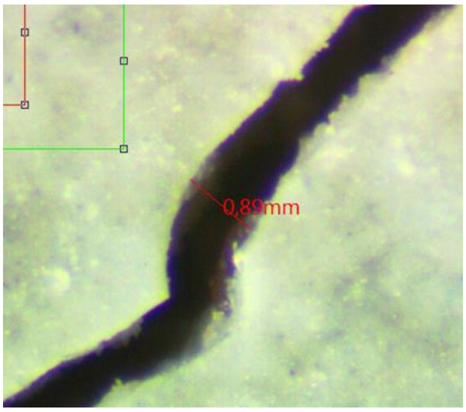
Mixture Type	Crack width after heating at 100 ºC (mm)	Crack width after heating at 200 ºC (mm)
SCC00HDPE	-	-
SCC05HDPE	0.27	0.42
SCC10HDPE	0.77	1.50
SCC20HDPE	0.89	2.05
SCC30HDPE	1.05	2.25

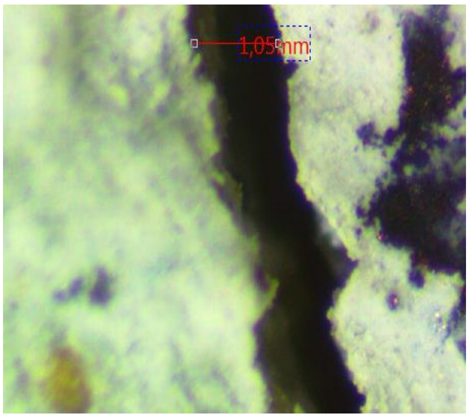




a) SCC05HDPE at 100 ºC

b) SCC10HDPE at 100 ºC

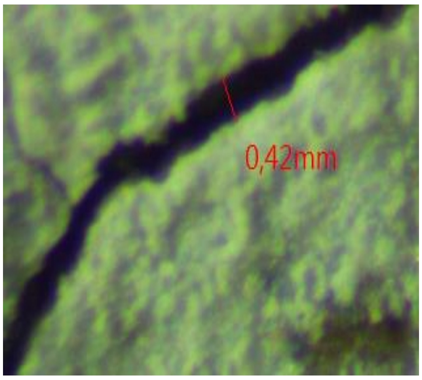




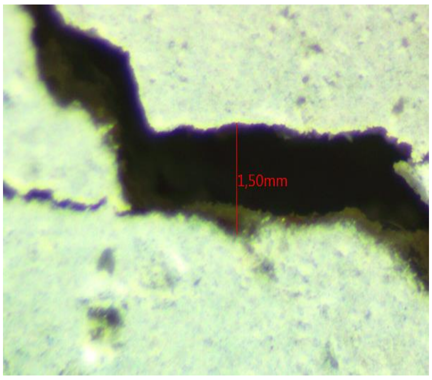
c) SCC20HDPE at 100 ºC

d) SCC30HDPE at 100 ℃

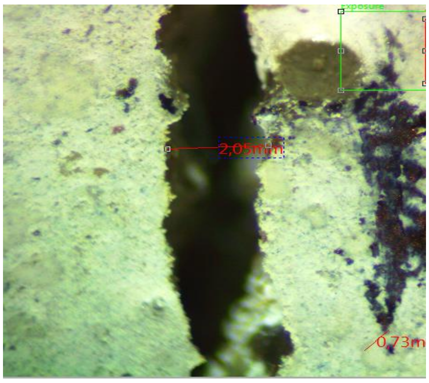
Figure 4.17: Cracks after Heat Exposure at 100 ºC



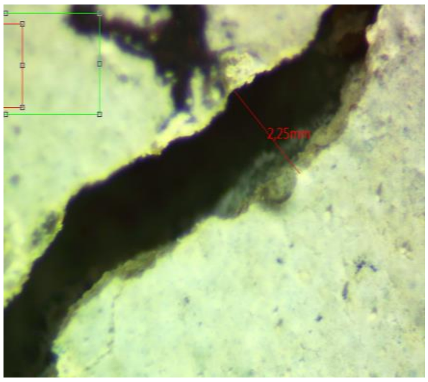
a) SCC05HDPE at 200 ºC



b) SCC10HDPE at 200 ºC



c) SCC20HDPE at 200 ºC



d) SCC30HDPE at 200 ºC

Figure 4.18: Cracks after Heat Exposure at 200 ºC

4.8.6 Relationship between f_c' and UPV before and after Degradation Tests

Figure 4.19 provide the relationship between f_c' and ultrasonic velocity test before and after exposure at two heating 100 ºC and 200 ºC. It can be seen from Figure 4.19 that the specimens that haven't exposed on high temperature has highest UPV and compressive strength (higher concrete quality), while the compressive strength decreases with decreasing of UPV and vice versa. In addition, compressive strength and UPV results deteriorated with increasing of HDPE replacement level and heat temperature.

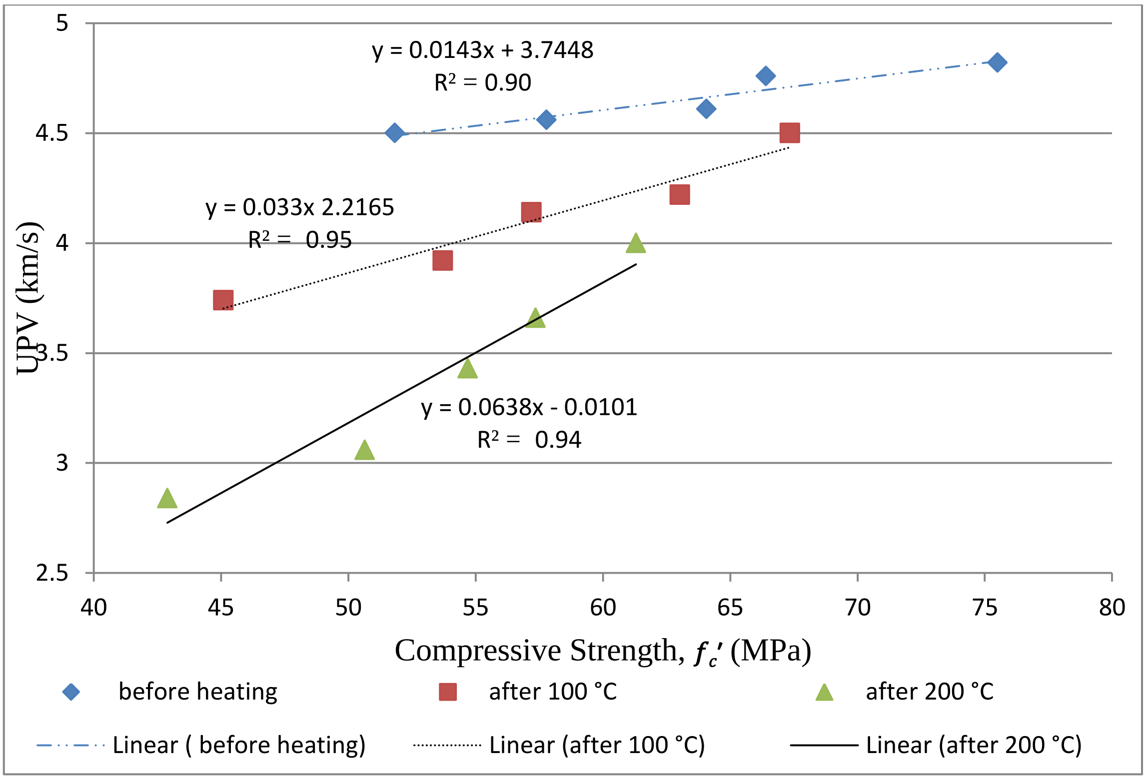


Figure 4.19: Relationship between f_c' and UPV before and after Heat Exposure.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The aim of this study is to investigate the influences of HDPE incorporation in different replacement levels 0, 5, 10, 20, and 30 % on SCC after being tested by fresh and hardened tests. The sample with 0 %HDPE replacement level was used as control sample. Accordingly, several conclusions have been made.

1. The fresh SCC properties have been affected negatively by the partial replacement of HDPE by coarse aggregate. A slight workability decrement has been detected after applying the workability tests (slump-flow, V-funnel, and L-box). However, the required workability of SCC was achieved up to 30 % HDPE replacement level.
2. Incorporation of HDPE aggregate in concrete reduces the compressive strength. It reached 26% reduction in f_c' at 30% HDPE replacement level.
3. In the same trend as compressive strength, the splitting tensile strength also decreased with the increasing of HDPE replacement percentage to hit 26 % as maximum reduction.
4. Partial HDPE replacement enhanced the ductility of SCC and makes it more deformable; however, it decreases flexural strength up to 16%.
5. As HDPE replacement decrease the Ultrasonic pulse velocity of samples due to the higher void rate and cracks which formed compared to control one.

6. As HDPE have lower density than natural coarse aggregate, the incorporation of HDPE in the concrete reduce HDPE-SCC weight. Therefore, it’s promising to produce lightweight concrete.
7. After the 100 and 200 ºC heat exposure, stereo-microscope observations showed appearance of surface cracks on the samples. The width of cracks increase according to two factors:
    - Increasing in temperature degrees.
    - Increasing in HDPE content in the samples.
8 Heat exposure showed decrement in UPV, compressive strength, and splitting tensile strength results. In addition, the results decreased further with the increasing of HDPE replacement level.

5.2 Recommendation for Future Studies

1. It’s important to study the combined effects of HDPE as coarse aggregate replacement and recycled HDPE fibers in concrete as additive.
2. Investigation for combined effects of fly ash and silica fume with HDPE coarse aggregate replacement on mechanical and physical properties of SCC.
3. Research for the most accurate percentage between 10 % and 20 % of HDPE replacement in order to determine the optimum HDPE-SCC.
4. In this study, hydrophobic plastic play a main role in mechanical loss of the concrete. Hence, it’s recommended to search for hydrophilic substance to cover the surface of HDPE as dipping the plastic aggregate in slurry to strengthen ITZ strength.
5. Studying the durability properties of SCC-HDPE concrete such as water permeability, rapid chloride permeability, creep, plastic shrinkage and drying shrinkage, resistance to freezing and thawing, and degradation test at elevated temperatures.

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