# BEHAVIOUR OF
# STEEL FIBER REINFORCED CONCRETE
# AND
# HIGH PERFORMANCE CONCRETE
# EXPOSED TO
# ELEVATED TEMPERATURE

SAHARA BINTI MOHD SARIF

B. ENG (HONS.) CIVIL ENGINEERING

UNIVERSITI MALAYSIA PAHANG

**UNIVERSITI MALAYSIA PAHANG**

**DECLARATION OF THESIS AND COPYRIGHT**

Author's Full Name : **SAHARA BINTI MOHD SARIF**

Date of Birth : **20 NOVEMBER 1995**

Title : **BEHAVIOUR OF STEEL FIBER REINFORCED CONCRETE (SFRC) & HIGH PERFORMANCE CONCRETE (HPC) EXPOSED TO ELEVATED TEMPERATURE**

Academic Session : **2017/2018**

I declare that this thesis is classified as:

| | | |
|---|---|---|
| ☐ | CONFIDENTIAL | (Contains confidential information under the Official Secret Act 1997)* |
| ☐ | RESTRICTED | (Contains restricted information as specified by the organization where research was done)* |
| ☑ | OPEN ACCESS | I agree that my thesis to be published as online open access (Full Text) |

I acknowledge that Universiti Malaysia Pahang reserves the following rights:

1. The Thesis is the Property of Universiti Malaysia Pahang
2. The Library of Universiti Malaysia Pahang has the right to make copies of the thesis for the purpose of research only.
3. The Library has the right to make copies of the thesis for academic exchange.

Certified by:

| | |
|---|---|
| _______________________ | _______________________ |
| (Student's Signature) | (Supervisor's Signature) |
| **951120-12-5750** | **DR GUL AHMED JOKHIO** |
| New IC/Passport Number | Name of Supervisor |
| Date: **JUNE 2018** | Date: **JUNE 2018** |

NOTE : * If the thesis is CONFIDENTIAL or RESTRICTED, please attach a thesis declaration letter.

# THESIS DECLARATION LETTER (OPTIONAL)

Librarian,
*Perpustakaan Universiti Malaysia Pahang*,
Universiti Malaysia Pahang,
Lebuhraya Tun Razak,
26300, Gambang, Kuantan.

Dear Sir,

CLASSIFICATION OF THESIS AS RESTRICTED

Please be informed that the following thesis is classified as RESTRICTED for a period of three (3) years from the date of this letter. The reasons for this classification are as listed below.

Author's Name
Thesis Title

Reasons (i)

(ii)

(iii)

Thank you.

Yours faithfully,

______________________________
(Supervisor's Signature)

Date:

Stamp:

Note: This letter should be written by the supervisor, addressed to the Librarian, *Perpustakaan Universiti Malaysia Pahang* with its copy attached to the thesis.

*(Please take out if not related)*

## SUPERVISOR’S DECLARATION

I/We* hereby declare that I/We* have checked this thesis/project* and in my/our* opinion, this thesis/project* is adequate in terms of scope and quality for the award of the Bachelor Degree of Civil Engineering

(Supervisor’s Signature)

Full Name : DR GUL AHMED JOKHIO

Position : LECTURER

Date : 11 JUNE 2018

**STUDENT'S DECLARATION**

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

_______________________________

(Student's Signature)

Full Name : SAHARA BINTI MOHD SARIF

ID Number : AA14152

Date : 11 JUNE 2018

BEHAVIOUR OF
STEEL FIBER REINFORCED CONCRETE &
HIGH PERFORMANCE CONCRETE
EXPOSED TO ELEVATED TEMPERATURE

SAHARA BINTI MOHD SARIF

Thesis submitted in fulfillment of the requirements
for the award of the
Bachelor Degree in Civil Engineering

Faculty of Civil Engineering and Earth Resources

UNIVERSITI MALAYSIA PAHANG

JUNE 2018

## ACKNOWLEDGEMENTS

Thank you to Allah Almighty who enabled me to research on this topic. I appreciate the patronage and moral support extended with love by my parents whose financial support and intense encouragement made it possible for me to complete this research study.

I express my heartiest gratitude to my respected supervisor Dr. Gul Ahmed Jokhio, the lecturer of Civil Engineering for his wholehearted guidance and help for completing this thesis.

I am deeply indebted to my praised fellow friends from faculty Civil Engineering for their priceless help in preparing this research. As you know, my joy knows no bounds in expressing my gracious gratitude to my best friends for lend a hand throughout the course of this research work.

I humbly extend my thanks to all concerned persons who co-operated with me in this regard.

# ABSTRAK

Konkrit bertetulang gentian keluli (SFRC) dan konkrit prestasi tinggi (HPC) digunakan secara meluas dalam unsur-unsur struktur bangunan seperti lata, lantai perindustrian dan lain-lain dengan meningkatkan sifat-sifat mekanikal struktur bangunan. Secara amnya, suhu tinggi adalah masalah yang serius bagi semua struktur konkrit dan merosakkan kesan pada tahap struktur akibat pendedahan kepada api, jika berlaku kebakaran. Dalam kerja percubaan ini mempunyai aspek yang menumpukan kepada suhu tingkah laku konkrit asas konkrit pada suhu tinggi termasuk kekuatan sisa. Selepas tertakluk kepada suhu pemanasan tinggi yang berbeza, antara suhu bilik dan 240°C, kekuatan konkrit bertetulang yang diperkuat dengan gentian keluli 4% (SFRC) dan kekuatan residu konkrit (HPC) yang tinggi telah disiasat. Bagi setiap jenis konkrit 18 set untuk konkrit biasa (PC), konkrit prestasi tinggi (HPC) dan konkrit bertetulang gentian keluli (SFRC) kiub telah dibuat. Spesimen-spesimen ini telah diuji untuk kekuatan mampatan pada suhu tinggi iaitu suhu bilik dan 240°C selama satu jam dalam keadaan panas sebaik sahaja keluar dari oven. Keputusan dianalisis dan kesimpulan akhir diambil.

## ABSTRACT

Steel fiber reinforced concrete (SFRC) and high performance concrete (HPC) are widely used in the structural elements of buildings such as slabs, industrial floors and others by enhancing the mechanical properties of structural elements of buildings. Generally, high temperature is serious problems for all concrete structures which drive in a mechanical decay of the concrete and even damaging effects at the structural level due to exposure to the flames, in case of fire. In this experimental work has an aspect which focused on basic mechanical behavior of concrete at high temperature including residual strength. After being subjected to different elevated heating temperatures, ranging between room temperature and 240ºC, the compressive strength of concrete reinforced with 4% steel fiber reinforced concrete (SFRC) and high performance concrete (HPC) residual strength have been investigated. For each type of concrete 18 sets for plain concrete (PC), high performance concrete (HPC) and steel fiber reinforced concrete (SFRC) of cubes have been cast. These specimens have been tested for compressive strength at elevated temperatures of room temperature and 240ºC for one hour in hot condition immediately after taking out from oven. The results are analysed and final conclusion are drawn.

## TABLE OF CONTENT

## LIST OF TABLES

## LIST OF FIGURES

## LIST OF ABBREVIATIONS

| | |
|---|---|
| HPC | High performance concrete |
| SFRC | Steel fiber reinforced concrete |
| PC | Plain concrete |
| SC | Standard concrete |
| FRSC | Fiber reinforced standard concrete |
| DoE | Design of experiments |
| OPC | Ordinary Portland cement |
| BS | British standard |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

The construction industry mostly uses steel fiber reinforcement in high performance concrete in applications such as tunnel lining and road paving. High performance concrete (HPC) is one of more durable and stronger materials concreted compare to conventional concrete due to the admixtures used in its proportion such as fly ash, super plasticizers and silica fume. The term ‘High performance concrete’ is also used because the mixture and proportion of this concrete are incompatible with conventional concrete. Hence, HPC is designed with high strength, high modulus elasticity, high durability and long life in severe environment. Steel fibre reinforced concrete can be designed as a composite material made with Portland cement, aggregate, and discrete discontinuous steel fibres. The real contribution of the steel fibre is to increase flexural, compress, tensile, and shear strength; toughness, and crack resistance by enhancing the properties of steel fibre reinforced concrete composite material.

Generally, the structural member design need to fulfil the requirements of serviceability and safety limit states for various environmental conditions. Fire is one of the major problems for high performance concrete structural members. This is because high performance concrete cannot sustain high temperature at extended periods of time. Although steel fibre doesn’t provide positive impact from fire-endurance point of view; based on previous research, it has been concluded that steel fibers have an impact on the spread of cracking and improve the performance of concrete after exposure to elevated temperature.

The performance of a concrete structural member exposed to fire is subject to thermal, mechanical and deformation properties of concrete of which the member is composed.

As a result, the properties of concrete change significantly within the members corresponding with building fires. The effect of temperature on these properties is different hence, it depends on the composition and characteristics of concrete. At both room and high temperature, the strength of concrete has significant impact due to its properties and the properties of high performance concrete (HPC) vary more with temperature compared to conventional concrete. This change is significantly more to mechanical properties that are influenced by strength, moisture content, density, heating rate, amount of silica fume and porosity.

In practice, fire resistance of structural members is evaluated mainly through the standard fire test, which is performed according to the specifications given by IS standard. When a structural member is subjected to a defined temperature-time exposure during a fire, this exposure will cause a predictable temperature distribution in the member. Increased temperatures cause deformations and property changes in the constitutive materials of a structural member.

## 1.2 Problem Statement

Usually the strength of the steel fiber decreases under high temperature and this happens during fire hazard. The strength of the steel fiber will reduces when burning. So, in order to investigate the performance of steel fiber reinforcement in high performance concrete (HPC) at elevated temperature, it is necessary that fire resistance tests for different elevated temperatures are conducted.

## 1.3 Research Objectives

The objective of this research study is to generate experimental data to aid the provision of a fire resistance rating for steel fiber reinforced concrete in high performance concrete (HPC). The main objectives are:

1. Study the effect on steel fiber reinforced concrete (SFRC) of exposure to elevated temperatures.

2. Study the behaviour of high performance concrete (HPC) at elevated temperature.

## 1.4 Scope of Work

The study will do the testing analysis for the steel fiber reinforced high performance concrete where exposing them to elevated temperatures at room temperature and 240ºC. All the specimens will be test in the laboratory. The experiment study included 18 cubes of 150 mm size for each type of concrete of which steel fiber reinforced concrete and high performance concrete. The compressive strength tests will be supervise to know the strength properties of the mixes.

| Samples | SFRC | | HPC | | PC | |
|---|---|---|---|---|---|---|
| Compressive Test | Room temp. | 240º C | Room temp. | 240º C | Room temp. | 240º C |
| | 3 | 3 | 3 | 3 | 3 | 3 |

Table 1.4.1: Number of specimens for each test

Principles of DoE method of mix design used to estimate the concrete mix proportion. Concrete mix proportion is 1:1.5:4 with water cement ratio of 0.47. The cement use is Ordinary Portland Cement (OPC). The fine aggregate use is 70% passing 600 µm sieve (uncrushed) with uncrushed maximum aggregate size of 20 mm. The test use is 30 N/mm² of characteristic compressive strength at 28 days. Next, provide straight fibers of 0.5 mm diameter and 50 mm length with 4% fibers by weight of concrete is added to the concrete mix (standard concrete).

| Mixes | Quantity per m³ of concrete | |
|---|---|---|
| | Standard Concrete | Standard Fiber Reinforced Concrete |
| Cement | 340 kg | 340 kg |
| Fine Aggregate | 515 kg | 515kg |
| Coarse Aggregate | 460 kg (10 mm)<br>925 kg (20 mm) | 460 kg (10 mm)<br>925 kg (20 mm) |
| Fibers | - | 96 kg |
| Super-plasticizer | 2.05 L | 2.05 L |
| Water | 160 L | 160 L |

Table 1.4.2: Total quantities used in experimental work

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Steel Fiber Reinforced Concrete (SFRC)

Fiber reinforced concrete (FRC) is a mixture of cementing concrete with amount of quantity of distributed small fibers. The addition of a numbers of small fibers in the FRC can improve concrete properties in all directions. Fibers function as to transfer load to the internal micro cracks. Micro cracks occur before the structure loaded that caused by drying shrinkage and other causes in volume change in conventional concrete. There are several types of FRC and steel reinforced concrete is one of it. Steel fiber reinforced concrete (SFRC) known as composite materials with additional of steel fibers randomly dispersed in small percentages such as between 0.3% and 2.5% by volume in conventional concrete (Reeta et al, 2016).

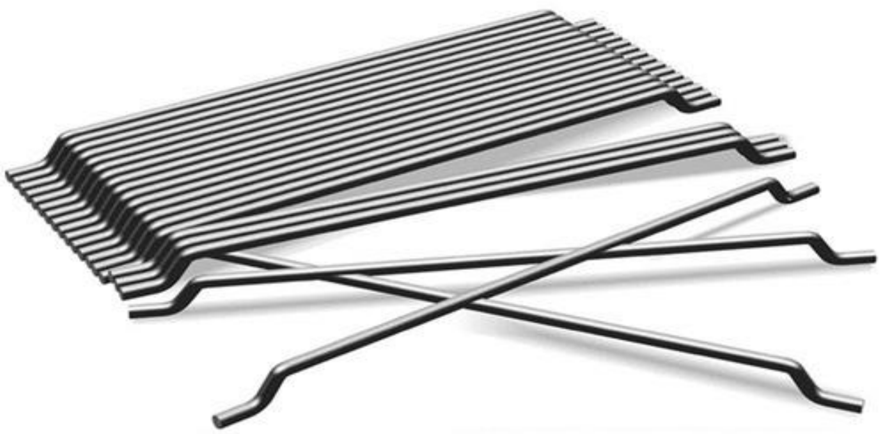

Figure 2.1.1 Steel fibres

Based on previous investigation, the addition of steel fibers into the concrete improved the mechanical properties of concrete. The results present that the compressive strength, modulus of elasticity and Poisson's ration increased to the maximum due to the addition of steel fibers found at less than 10% in numerous grades of concrete (35, 65 and 85 MPa). In addition, the strain also increased according to the peak compressive strength found about 30% in different grades of concrete (35, 65 and 85 MPa).

## 2.2 Performance of Steel Fiber Reinforced Concrete at high temperatures

From the past research on high performance concrete under elevated temperatures by obtained the experimental test results from compression tests and mass loss measurements. The performance of HPCs under elevated temperatures was observed in terms of spalling, color and cracking observation on the outer and inner surfaces of the specimens; mass losses and residual strength (A.H. Akca, 2013).

Firstly, some specimens were observed under explosive spalling when the specimens exposed to 600ºC and spalling started at 500ºC. Based on Han result, no explosive spalling was observed when polypropylene fibers were used except some specimens. Thus, microstructure of HPC can be observed and explained due to explosive spalling in the fibrous specimens. Besides, the experiments was done using HPC with a compressive strength of 80 MPa shows that PP fiber melted above 170° and explosive spalling happen at 0.24 water-to-binder ratio of concrete was so dense that it could still keep the water pressure high enough. Hence, the addition PP fiber can resist against explosive spalling by the contribution of air entrainment (A.H. Akca, 2013).

Next, mass losses of the specimens after exposure to high temperatures mainly caused from water and carbon dioxide transport and loss. At specimens exposed to 300ºC, 600ºC and 900ºC, an average mass losses recorded were 5.2%, 9.8% and 12.9% respectively. Thermogravimetric was observed and the analyses also similar and the serious loss of strength after 600ºC. Futhermore, residual strength also being observed by conducted the compressive strength test. The result shows that the concrete specimens exposed to lower temperatures are stronger than the specimens exposed to higher temperatures (A.H. Akca, 2013).

According Kodur V. K. R. test results, the strength of the fibre reinforced concretes made with siliceous as well as with carbonate aggregate was higher compared to plain carbonate aggregate concrete. The strength of both fibre reinforced concretes more than the initial strength of the concretes at temperatures up to 400°C, although the strength of the concretes remain below the original strength. Besides, fibre reinforced concrete reach higher ultimate strains than plain concrete at elevated temperatures. The increase in strain can be attributed to the increase in crack volume due to the steel, which has a greater thermal expansion than the concrete. Next, the modulus of elasticity is more affected through the formation of cracks than the compressive strength. The formation of micro-cracks due to shrinkage of the cement paste cause to increment the compressive strength of the concrete, the increase in strains due to the steel fibres. Thus, results in a decrease in the modulus of elasticity, which the rate of decrease in the modulus of elasticity is highest in the temperature range 0 to 300°C (Kodur V. K. R., 2014).

Based on J Novak and A Kohoutkova previous research study on fibre reinforced concrete exposed to elevated temperature, the use of steel fibers seems to be beneficial for concrete composites exposed to high temperature due to melting point of steel is relatively high in comparison with other materials. In fact, the addition of steel fibers in a concrete mix leads to an improvement in both mechanical properties and resistance to heating effects in comparison with unreinforced concrete. The experimental result shows that the compressive strength of steel fiber reinforced reactive powder concrete and geopolymer concrete successively increases when the material is heated up to 200-300°C, then start to decrease as temperature further increase. At 200°C and 400°C, the compressive strength of reactive powder concrete with 1% steel content is higher than at room temperature and collapse when temperature exceed 500°C. Moreover, 2% and 3% steel fiber content particularly increase compressive strength from 200°C to 300°C which then slowly decreases as the temperatures reach 400°C and above. Hence, a higher content of steel fibers cannot improve the compressive strength of concrete composites at elevated temperatures. In addition, SFRC has the higher toughness after high temperature exposures when compared to the initial values of unheated concrete. SFRC weakens and experienced reduced stiffness with the degradation depending on the type, aspect ratio and volume fraction of the fiber as the temperature rise and the rduction in modulus elasticity is more noticeable than the reduction in compressive strength for the same heat treatment. Steel fiber aggregate concrete shows the identical behaviour and loses stiffness much faster exposure to elevated temperature. As a result, peak strains slowly increases together with temperature. The increment in peak strains along with steel fiber content does not particularly vary between ambient temperature and 200°C. A higher steel fiber content usually is related with a higher peak strain when temperatures exceed 200°C. Furthermore, the inclusion of steel fibers does not remove the spalling tendency of concrete mixtures (J Novak and A Kohoutkova, 2017).

## 2.3 Performance of Steel at high temperature

Based on the previous research shows that effect of temperature on steel can be classified into physical and mechanical properties of steel which are density, specific heat, thermal conductivity, yield strength and tensile strength. For the physical properties of steel, the density of steels decreases about 30% with increasing temperatures through melting process. From research analysis of relationship modulus of elasticity and types of reinforcing steel, concluded that the modulus elasticity decreases nearly linear with increasing temperatures (U. Schneider, 1981).

Previous investigations on tensile strength properties of steels at high temperatures shows that strength and ductility in steels changes due to the high temperatures. The lower the carbon content was quickly reached the minimum tensile strength with first rise in temperatures and the maximum strength occurred with the higher carbon steels compare to medium or low-carbon alloys. From time to time, elastic properties decrease with increase in temperatures and changes in ductility by measured the elongation and reduction area. At elevated temperatures, the elongation decreases slowly and decreases rapidly to a minimum as occurring between 125°C and 200°C. Then, the elongation increase rapidly. Reduction area decreases above the room temperature, then fall rapidly to a minimum between 205°C and 315°C (French).

## 2.4 Performance of Concrete at high temperature

The test program on mechanical behaviour of concrete at high temperature has been conducted in China. There are includes compressive strength, tensile strength, poisson’s ratio and constitutive relationship where the compressive strength is the basic one of the mechanical behaviour of concrete. However, the strength of concrete under high temperatures vary between concrete grades, types of aggregate, mix proportions, curing condition, heating parameters and cooling regimes in the test results. Based on relationships between axial compressive strength of concrete and temperatures, it shows that the compressive strength of concrete decreased a bit and then increased a bit as the temperature goes up from room temperature to 400°C. It also considered as a constant and it suddenly decrease highly. Then, it falls to less than 20% of that at room temperature and 800°C. Hence, lightweight aggregate concrete has higher fire resistance compare to ordinary concrete because above 400°C its strength is gentle. The strength degradation of concrete with different aggregate does not act the same under elevated temperatures (J. Xiao, 2003).

Besides, behaviour of concrete both under and after high temperature for the type of aggregate, curing condition and test method also can influenced on the stress-strain relationship of concrete. According Nan et al. test and analysis, concluded that at elevated temperature the strength under a fixed stress condition was the upper limit of concrete strength, while the lower limit with loading condition was the strength under a constant high temperature. For example, ranged from 600°C to 800°C has the upper strength limit was about 1.4-2.5 times of the lower strength limit. In addition, the peak strain of concrete at high temperature has greater while the strength and elastic modulus of concrete also higher under stress condition (J. Xiao, 2003).

Q. Ma et al. carried out investigations on mechanical properties of concrete at high temperature such as compressive strength, flexural strength, splitting tensile strength and modulus of elasticity; stress-strain relationship, physical and chemical changes; and spalling. When concrete exposed to high temperature, compressive strength of concrete will reduces. After heating concrete to high temperature, residual compressive strength experiences three main phase included the compressive strength of concrete keeps constant or even increases a bit at 300°C, while 300°C between 800°C compressive strength of concrete reduces drastically. At 800°C afterwards, nearly all the compressive strength of concrete has been lost. For the flexural strength, splitting tensile strength and modulus elasticity of concrete decreases, but at almost linear rate when concrete exposed to elevated temperatures. Next, water evaporation occurred through hydration products lose their free water and physically absorbed water completely and concrete start to lose their chemically bonded water at 105°C. At 400°C, capillary water completely lost and this particularly happened for high strength concrete as its low permeability resists moisture flow. As elevation of temperature increases porosity and pore size of cement and concrete caused by water evaporation and the chemical changes of hydration products. Microstructure has been observed up to 200°C and no micro-cracks are founded in either hardened cement matrix or interfacial transition zone. As the temperature increases to 400°C, micro-cracks start propagate in cement matrix and their intensity rises with temperature. At high temperature, micro-cracks start to develop in hardened cement matrix and aggregates, thus the hardened cement matrix expands first and then shrinks due to the loss of water. Meanwhile, the aggregate keep expansion during the whole heating. Above 1000°C where temperature is very high, porosity and microstructure of concrete are tiny and better than those at lower temperature. Hence, mechanical properties of concrete at very high temperature was better compare to those at a lower temperature. In addition, reduction in mechanical properties of concrete structure occurred due to spalling of concrete at elevated temperature. The mechanisms of spalling of concrete could be explained from vapour pressure in pores and thermal stresses aspects. It happened when high temperature hit the concrete surface then, a portion of water will be vaporised and move out from the concrete into atmosphere. However, certain amount of water also vaporised and move opposite to the inner part of concrete. If the heating rating is too high, the vapour layer cannot escape fast enough which may cause a large increase of pore pressure in the concrete. Spalling of concrete would occur the whole process of the thermal spalling of concrete, if the tensile stress of concrete could not resist the pore pressure which gives the pore vapour pressure. Based on the experimental test shows that maximum pore pressure mostly occurred in the inner part of concrete at high temperature. Moreover, in high strength concrete has maximum pore pressure compared to the normal strength concrete (Q. Ma et al., 2015).

Researched study of Cheng et al. observed that, there were several factors influencing the performance of concrete subjected to high temperature which is type of aggregate. Type of aggregate also give an effects on compressive strength, flexural strength, splitting tensile strength and modulus elasticity of concrete at high temperature. Based on result experiment, the concretes made of siliceous aggregates like granite shows negative mechanical properties at high temperature compared to the concretes manufactured by using lime stones and dolomite these calcareous aggregates. Besides, the concrete made of calcareous aggregates was larger increase in strains compared to the siliceous aggregates concrete. Hence, it explained that the concrete with calcareous aggregates has better performance of the concrete at high temperature (Q. Ma et al., 2015).

## 2.5 Performance of High Performance Concrete at high temperature

According test result of A. Lau and M. Anson shows that temperature effects on compressive strength, when the specimens heated at specified temperatures. It can be observed that the reduction is found when the concrete is heated below 400°C. However, the decrease in strength is considerable between 400°C and 800°C but then remains useful at around the 30 MPa mark for HPC. At 1000°C and 1200°C maximum temperatures, all mixes have negligible strength of between 4 MPa and 12 MPa; and between 6 MPa and 19 MPa. From microstructure analysis, the porosity of the concrete mixes has been observed after the concrete specimens exposed to various maximum heating temperatures. As the maximum heating temperature increases, the porosity also increases. Thus, concrete specimens were found to have higher intrusion volumes and larger pore sizes when subjected to high maximum temperatures. In HPC there was no evidence of spalling for concrete samples during the simulated fire tests even though spalling has been identified as a problem with HPC by other researchers (A. Lau, 2006).

Based on A. H. Akca and N. Ozyurt Zihnioglu result experimental, HPC experienced explosive spalling at approximately 500°C which done based on the sound of explosive spalling. Explosive spalling was observed in these fibrous specimens and this condition can be explained throughout dense microstructure of HPC. According to Peng on his previous researched using HPC with a compressive strength of 80 MPa, despite of the interconnected channel system formed by PP fiber melted above 170°C. 0.24 water to binder ratio of concrete was too dense that it could still keep the water pressure high enough to result in explosive spalling. Next, residual strength increases when air entraining admixture was used for all the samples with a thickness of 5 cm when the samples heated to 300°C and 600°C. Thus, air entrainment affects the residual compressive strength of concrete. Besides, when the samples heated up to 600°C there was no cracking was oserved on the inner surfaces of the samples. Inner cracks both in aggregates and cement paste were only noticed in the samples which were heated to 900°C (A. H. Akca & N. O. Zihnioglu, 2013).

As stated by P. Pimienta et al., the crystal transformation occurred mainly in the aggregates which called degradation reactions of cement paste by progressive breakdown in the structure of the concrete. They occur more usually in the hardened cement paste hydrated components, but also in the aggregates depending on the type of aggregate concerned. The chemical reactions usually take the form of dehydration of cement paste components such as CSH and portlandite followed with water vapour expulsion at temperature from 100°C to 500°C.  Next, crystalline transformation of aggregates occurs at higher temperatures up 800°C and concrete has melt then into a liquid above 1300°C-1400°C (P. Pimienta et al., 2017).

# CHAPTER 3

# METHODOLOGY

## 3.1 Introduction

In this research study, the experimental data base will be conduct for compressive strength of high performance concrete and steel fiber reinforced standard concrete which are exposed to elevated temperatures at room temperature and 240ºC. In the previous research work, the compressive strengths of Standard Concrete and Standard Fiber Reinforced Concrete were measured after exposing them to elevated temperatures for one hour period and the testing made in hot condition directly after taking out from the oven. In order to produce High Performance Concrete and Steel Fiber Reinforced Concrete, the major work need to prepare in designing an appropriate mix proportion based on the DoE method which is British method of concrete mix design and it is being used in United Kingdom and other parts of the world.

## 3.2 Materials and mix design

Materials: steel fibers is used with 0.41 w/b ratios and straight fibers of 0.5 mm diameter and 50 mm length. Super-plasticizer is used about 2.05 L as an admixture.

In this experimental work, the concrete mix design by DoE method will be used to carry out field experiments. The design begins by following the flow process which is divided into five stages. Each of these stages deals with a particular aspect of the design and ends with an important parameter or final unit proportions. These stage included:

Stage 1: Deals with strength leading to the free-water/cement ratio.

Stage 2: Deals with workability leading to the free-water content.

Stage 3: Combines the results of Stages 1 and 2 to give the cement content.

Stage 4: Deals with the determination of the total aggregate content.

Stage 5: Deals with the selection of the fine and coarse aggregate contents.

Concrete: The mix proportion is 1: 1.5: 4 with water cement ratio of 0.47. The slump required is between 10 and 30 mm. Ordinary Portland Cement (OPC) is the cement used and fine aggregate used is uncrushed about 70% passing 600 µm sieve. The coarse maximum aggregate used is uncrushed stone passing 20 mm sieve. Potable water of pH value 6.72 is used. The experimental works can be categorize in two stage:

Stage 1: Develop standard and high performance concrete of C30 mix which followed specifications given by British Standards (BS).

Stage 2: Study the compressive strength that exposed to vary temperatures by adding and without adding steel fibers.

## 3.3 Testing Procedures/ Mixing of Concrete

1. After prepare mix design proportions, all materials (cement, fine aggregate, coarse aggregate, steel fibers and water) and put them separately.

2. Add the coarse aggregate, fine aggregate, steel fiber and finally the cement in a mixer rotating.

3. Mix all the dry components uniformly for several minutes to ensure the cement cover all aggregate particles.

4. Add the water periodically to the mixture.

5. Allow all mix design proportions to mix for several minutes to ensure uniformity.

6. After the mixer turned off, check that no material is stuck to the blades of the mixer.

7. Step 1 until 6 is repeat without steel fibers in the mixture, then superplasticizer is add as an admixture for preparation high performance concrete.

8. The mixer is tilt and the concrete is place on a clean platform of 150 mm cubes size.

Figure 3.3.1: Process of Concrete Mixing

## 3.4 Sample Size

For the sample size, 18 cubes of 150 mm size for each type of concrete is cast to study the compressive strength of concrete. The concrete fill into 150 mm cube moulds and place the cube mould on table vibrator then, vibrate it for 1 minute. The surfaces of the cubes is level with a trowel and then mark for identification after the compaction is complete. After 24 hours of casting, these specimens is remould.

## 3.5 Curing of Samples

The curing process of the specimens conduct in a water tank for 28 days where these samples is store under water at room temperature until test at an age of 28 days. This curing process executed after the specimens is remould. All samples is remove from the curing tank after 28 days of casting and then, it place under laboratory air drying conditions until required for elevated temperature exposure or for any compressive test.

## 3.6 Samples Testing

The compressive strength test is supervise for the cubes sample after 28 days of curing process using compressions testing machine. After exposing the cubes to the relevant temperatures, then the cubes directly being test. Firstly, clean the bearing surface of the compression testing machine and place the cubes concentrically; and the load is applied to the opposite sides of the cube as cast. Increase the load slowly and continuously at a rate of approximately 140 kg/sq cm/minute until the resistance of the cube to the increasing load breaked down and no larger force can be sustain. Lastly, record the maximum load applied to the cube.

After that, the specimens will be expose to elevated temperature and testing in order to determine the strength of the cubes sample. Primarily, heat the samples in oven to specified temperatures for one hours. Then, test the samples for respective strength in hot condition directly after taking out of the oven.

In addition, the samples are test with room temperatures and 240ºC for one hour period. Firstly, place the samples on each tray of oven and set the target temperatures in the control panel after the samples put inside the oven.

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 Introduction

In this chapter, it more focus on result and discussion of this research that gained from the experimental work. All the results will present in tables, figures and graphs on the details data from the testing work such as compressive test.

## 4.2 Temperature Effects on Compressive Strength

Result compressive test for plain concrete (PC), steel fiber reinforced concrete (SFRC) & high performance concrete (HPC)

Plain Concrete (PC)

| ***Room temp.*** | | | |
|---|---|---|---|
| ***Load*** | *936.7 KN* | *1034.0 KN* | *1018.0 KN* |
| ***Stress*** | *41.63 MPa* | *45.96 MPa* | *45.27 MPa* |
| ***Average stress*** | *44. 29 MPa* | | |
| ***240°C (1 hour)*** | | | |
| ***Load*** | *980.8 KN* | *974.7 KN* | *921.7 KN* |
| ***Stress*** | *43.59 MPa* | *43.32 MPa* | *40.97 MPa* |
| ***Average stress*** | *42.63 MPa* | | |

Table 4.2.1: Compressive result for plain concrete

Based on Table 4.2.1 of compressive result for plain concrete above, the average stress at room temperature is 44.29 MPa and then the average stress decreased to 42.63 MPa after being heated at 240°C for only one hour. It shows that, the percentage reduction only 3.89% of compressive strength for plain concrete.

High Performance Concrete (HPC)

| ***Room temp.*** | | | |
|---|---|---|---|
| ***Load*** | *1057.504 KN* | *1011.473 KN* | *976.484 KN* |
| ***Stress*** | *47.0 MPa* | *44.95 MPa* | *43.40 MPa* |
| ***Average stress*** | *45.12 MPa* | | |
| ***240°C (1 hour)*** | | | |
| ***Load*** | *1021.072 KN* | *956.288 KN* | *941.047 KN* |
| ***Stress*** | *45.38 MPa* | *42.5 MPa* | *41.82 MPa* |
| ***Average stress*** | *43.23 MPa* | | |

Table 4.2.2: Compressive result for high performance concrete

Based on Table 4.2.2 of compressive result for high performance concrete above, the average stress at room temperature is 45.12 MPa and then the average stress decreased to 43.23 MPa after being heated at 240°C for only one hour. It shows that, the percentage reduction only 4.37% of compressive strength for high performance concrete.

Steel Fiber Reinforced Concrete (SFRC)

| ***Room temp.*** | | | |
|---|---|---|---|
| ***Load*** | *910.204 KN* | *849.836 KN* | *718.135 KN* |
| ***Stress*** | *40.45 MPa* | *37.77 MPa* | *31.92 MPa* |
| ***Average stress*** | *36.71 MPa* | | |
| ***240°C (1 hour)*** | | | |
| ***Load*** | *755.198 KN* | *802.384 KN* | *837.073 KN* |
| ***Stress*** | *33.56 MPa* | *35.66 MPa* | *37.20 MPa* |
| ***Average stress*** | *35.47 MPa* | | |

Table 4.2.3 Compressive result for steel fiber reinforced concrete

Based on Table 4.2.3 of compressive result for steel fiber reinforced concrete above, the average stress at room temperature is 36.71 MPa and then the average stress decreased to 35.47 MPa after being heated at 240°C for only one hour. It shows that, the percentage reduction only 3.49% of compressive strength for high performance concrete.

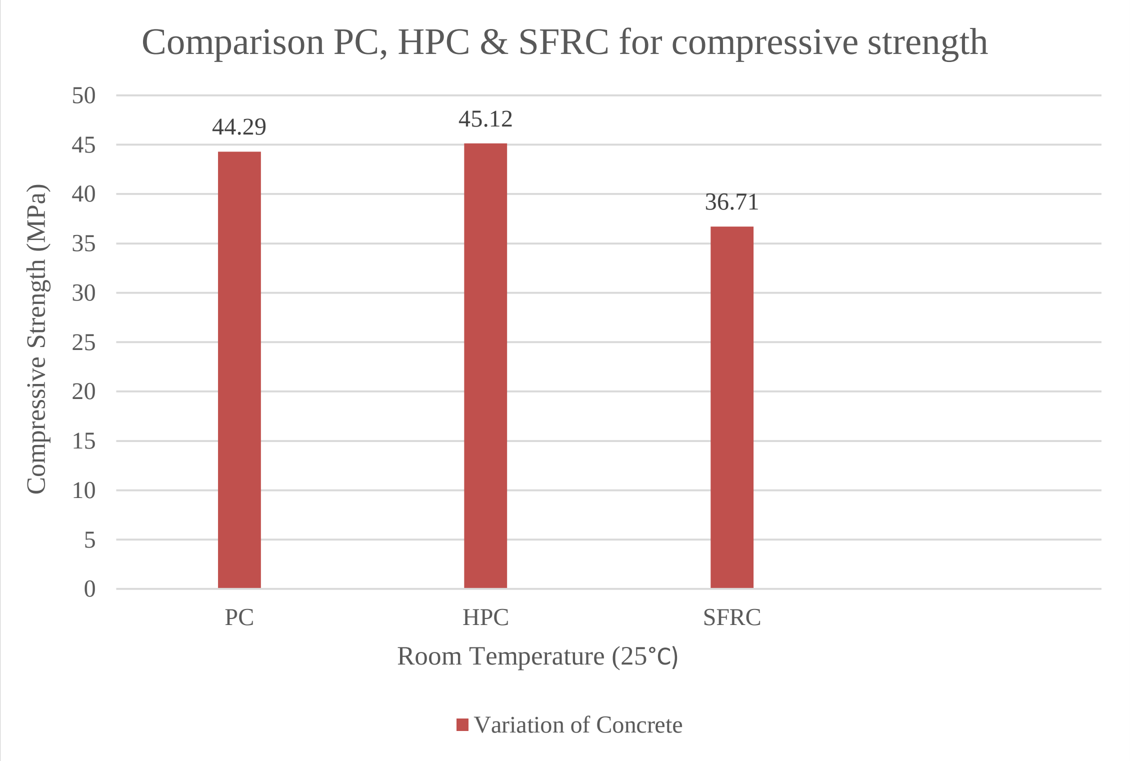


Figure 4.2.4 Compressive strength vs. room temperature at 25°C

The compressive strength results for room temperature specimens are shown in Figure 4.2.4. It can be observed that the variation in strength is noticeable for plain concrete (PC), high performance concrete (HPC) and steel fiber reinforced concrete (SFRC). Comparison strength between PC and HPC shows an increment in strength. However, the reduction in strength is considerable between PC and SFRC which shows that the addition of fibres unable gives increment in compressive strength.

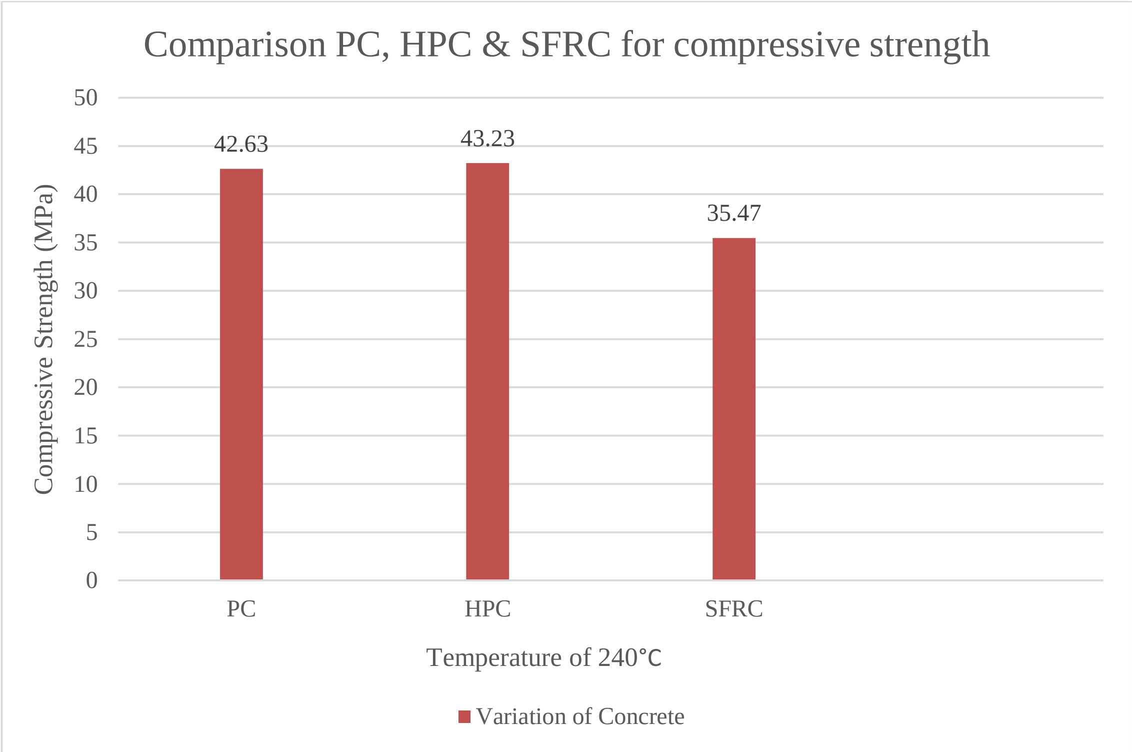


Figure 4.2.5 Compressive strength vs. temperature at 240°C

The compressive strength results for temperature at 240°C specimens are shown in Figure 4.2.5. It can be observed that the variation in strength is noticeable for plain concrete (PC), high performance concrete (HPC) and steel fiber reinforced concrete (SFRC). Compressive strength of HPC is higher than that of PC due to admixture (super-plasticizer) use in HPC. Generally, compressive strength of PC lies at 42 MPa while HPC lies at 43 shows a bit increment. Compressive strength for SFRC is lower than that of PC and HPC where the compressive strength of SFRC lie at 35 MPa. Therefore, it is deduced that there is no significant effect of fibers on compressive strength of concrete in 240°C temperature.

Based on previous research on, comparison of standard concrete (SC) and fibre reinforced standard concrete (FRSC) for compressive strength. SC and FRSC of the compressive strength specimens exposed to different elevated temperature is shown as percentage of 28 days compressive strength of SC at room temperature. The difference of compressive strength with temperature has been plotted as shown in Figure 4.2.6.

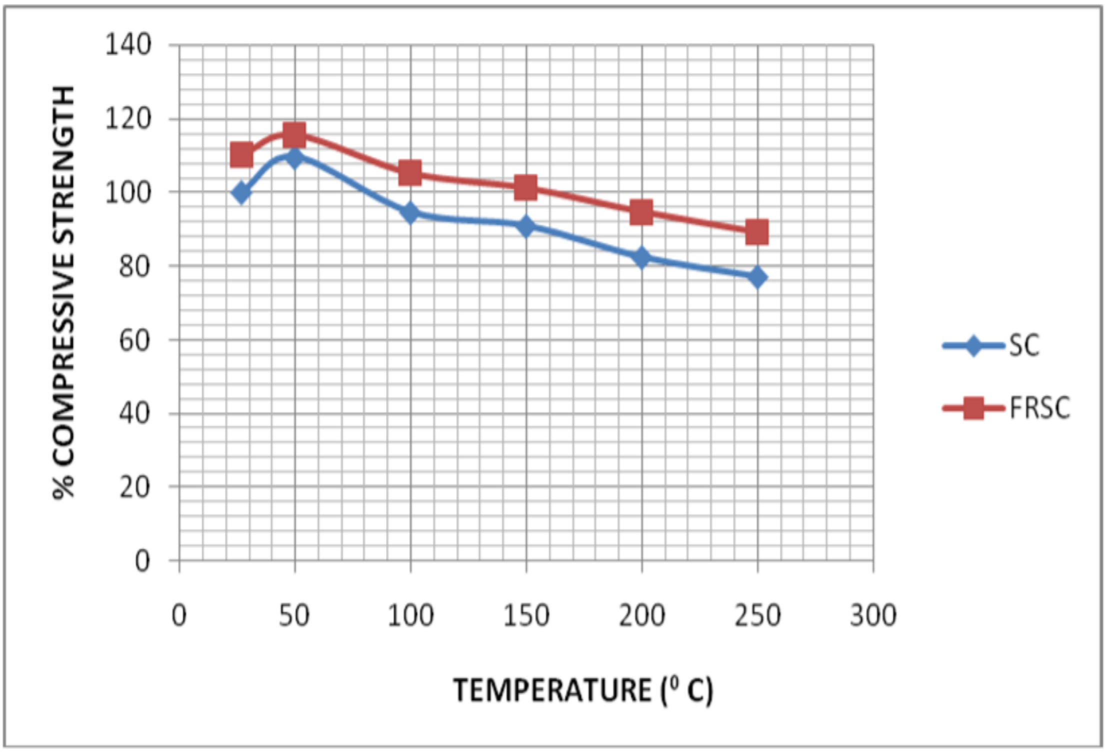


Figure 4.2.6 Comparison of difference compressive strength with temperature for Sc and FRSC

From Figure 4.2.6, it can be observed that FRSC shows more compressive strength than the SC at the all temperatures. FRSC maintained low reduction profile than SC as the temperature is increased which resulting in more percentage compressive strength after 100°C. The variation between compressive strength of FRSC and SC varies in the range is 6 to 10 percentage. It can be concluded that both standard concrete and fiber reinforced concrete are found an increase in compressive strength when exposed to a temperature 0f 50°C and found to loose compressive strength gradually beyond 50°C (K. Srinivasa, S. Rakesh, A. Laxmi, 2013).

Based on previous research, the overall results of high performance concrete (HPC) residual compression test observed that the concrete specimens exposed to lower temperatures are stronger than the specimens exposed to higher temperatures. The presence of admixture in the high performance concrete (HPC) effect on the residual compressive strength at various temperatures. Size of the specimens also affected the compressive strength with 10 cm height experienced good performance when the temperature was in increased up to 600°C. Thus, the residual strength of HPC increased by addition of air entraining admixture (AEA) but this positive effect was found irregular after 300°C. Moreover, variation percentage of AEA (0.5% and 1%) were used for this study also gives an effect on residual strength where the positive effect created by AEA was found to become irregular when the dosage was increases (A. H. Akca & N. O. Zihnioglu, 2013).

## 4.3 Discussion

In order to conduct this experimental, concrete mix design by principles of DoE method of mix design was implemented to achieved the design concrete mix, achieved the desire minimum strength, produce concrete as economically and achieve the desired durability by followed the process of mix design. The factors contributed to the strength concrete is influence of the constituent materials such as cement where the fineness cement will increase the strength and type of cement like RHPC/OPC. Water also contributed to the strength of concrete through water cement ratio for hydration process where the lower w/c, the greater compressive strength then curing conditions also influenced the strength of the concrete. Alternative reasons for using super-plasticisers in high performance concrete are increased fluidity, reduced water ratio, increase the strength of concrete and control the concrete shrinkage.

In this experimental work, the compressive strength result for plain concrete (PC), high performance concrete (HPC) and steel fiber reinforced concrete (SFRC) obtained comply with the designed characteristic strength which is 30 N/mm² at 28 days.

Based on Srinivasa, Rakesh and Laxmi (2013) experimental study, fiber reinforced standard concrete (FRSC) had more compressive strength compare to standard concrete (SC) at the all temperatures. However, the result for this experimental work shows that steel fiber reinforced concrete (SFRC) had lesser than compressive strength compare to plain concrete (PC) for both room temperature and 240°C as shown in Figure 4.2.4 and Figure 4.2.5. The comparison of previous study and experimental result showed many differences can be attributed to errors during conduct the experimental work such as:

1) During preparation of the concrete mix, the concrete mix of steel fiber reinforced concrete (SFRC) was done manually using hand using all the appropriate instruments because for each concrete mix must be add equal percentage of fibers which is 4% by weight of concrete (cube samples). Thus, the SFRC concrete mix cannot evenly mixed and gives effect to the residual strength (compressive strength). One factor that effect

plain concrete (PC) has higher compressive strength it because the concrete mix was fully mixed using concrete mixer.

2) The addition of percentage steel fibers in the concrete mix (SFRC) was not enough to increase the residual strength. It was observed that compressive strength of PC higher than SFRC for both room temperature and 240°C as seen in Figure 4.2.4 and 4.2.5. 4% of steel fiber by weight of concrete does not gives any positive effect to the compressive strength of SFRC. Hence, increase the percentage of steel fibers in the concrete mixture to double the toughness and gives positive effect to the compressive strength. So, behaviour of SFRC for both room temperature and 240°C can be observed clearly.

3) 240°C is the highest temperature was tested on cube samples which not shows high positive impact on SFRC and HPC. Increase the elevated temperature with more variation of temperatures to test compressive strength for high performance concrete (HPC). This because the result compressive strength had small variation between plain concrete (PC) and high performance concrete (HPC) for this present experimental work that can be seen in Figure 4.2.4 and 4.2.5.

4) During curing process, the moisture content also effect on concrete strength. It because the increasing compressive load on the concrete specimen during testing develops an increasing internal pressure, not only on solid components of the concrete, but also on the liquid in the pores, trying to squeeze the liquid out of the specimen. Since, the migration of water is not free due to the smallness of the capillary sizes, the hindrance produces a pressure on the contacting pore walls which increases as the external force on the specimen increases. When the concrete samples is near fully saturated, a small percentage of air in the pores cannot diminish the changes in pore pressure caused by loading. The higher the degree of saturation, the sooner the full saturation will be obtained, hence the measured compressive strength will be higher (Chen et al., 2012).

# CHAPTER 5

# CONCLUSION

## 5.1 Introduction

In this study, the result of compressive strength on steel fiber reinforced concrete (SFRC) and high performance concrete (HPC) to elevated temperature were presented. Comparison compressive strength for plain concrete (PC), high performance concrete (HPC) and steel fiber reinforced concrete (SFRC) were presented in Figure 4.2.4 and 4.2.5. SFRC were prepared in six samples with the use of steel fibers for both room temperature and 240°C. HPC also were prepared in six samples with 2.06 L super-plasticizer as an admixture for both room temperature and 240°C.

1) Decrease in compressive strength has been observed for both PC and SFRC when exposed to elevated temperature.

2) HPC get not so higher compressive strength compare to PC with addition of admixture in the concrete mix (super-plasticizer) when exposed to elevated temperature.

3) At room temperature and 240°C, SFRC are found to loose compressive strength gradually.

## 5.2 Recommendations

In order to improve the experimental work in this research, there are several recommendations should be implement for future experimental work such as:

1) Testing part should be done with more variation of elevated temperatures to observe more comparisons in result of compressive strength.

2) Increase the percentage of steel fiber used in the mixture to get better effect on heated concrete.

3) Increase the dosage of admixture used in the mixture of high performance concrete (HPC) to get additional effect on heated concrete.

## REFERENCES


1) Srinivasa Rao, K., Rakesh Kumar, S., & Laxmi Narayana, A. (2013). Comparison of Performance of Standard Concrete And Fibre Reinforced Standard Concrete Exposed To Elevated Temperatures. American Journal of Engineering Research (AJER). 2(3), pp-20-26.

2) Thomas, J. and Ramaswamy, A. (2008). Mechanical Properties of Steel Fiber Reinforced Concrete. Journal of Materials in Civil Engineering, 19(5), p. 385.

3) Drzymala, T., Jackiewicz-Rek, W., Tomaszewski, M., Galaj, J., and Sukys, R. (2017). Effects of High Temperature on the Properties of High Performance Concrete (HPC). Procedia Engineering, 172, p. 256-263.

4) Akca, A.H. & Zihnioglu N.O. (2013). High performance concrete under elevated temperatures. Construction and Building Materials.

5) Chen, B., Li, C., and Chen, L. (2009). Experimental study of mechanical properties of normal-strength concrete exposed to high temperatures at an early age. Fire Safety Journal.

6) Ryabchikov, A., Tamme, A., and Laurson, M. (2015). Investigation of Mechanical Properties of Steel Fibre Reinforced Concrete. Materials Science and Engineering.

7) Kodur, V. (2014). Properties of Concrete at Elevated Temperatures. ISRN Civil Engineering.

8) Iqbal, S., Ali, A., Holschemacher, K., and A. Bier, T. (2015). Mechanical properties of steel fiber reinforced high strength lightweight self-compacting concrete (SHLSCC). Construction and Building Materials, Volume 98, P. 325-333.

9) Preetha, V., Xavier, B., and Narayanan, K.P. (2014). Strength properties of steel fibre and glass fibre composites. International Journal of Civil Engineering and Technology (IJCIET), 5(12), pp. 188-193.

10) Yong Kim, G., Sun Kim, Y., and Gyu Lee, T. (2009). Mechanical properties of high-strength concrete subjected to high temperature by stressed test. Trans. Nonferrous Met. Soc. China, 19, s128-s133.

11) Ma, Q., Guo, R., Zhao, Z., Lin, Z., and Kecheng He. (2015). Mechanical properties of concrete at high temperature. Construction and Building Materials, 93, p. 371-383.

12) Merlo Construction, (2017). What is High-Performance Concrete. [online] Available at: https://www.merloconstructionmi.com/high-performance-concrete/ [2017].

13) Siddique, R. and N. Noumowe, A. (2010). An Overview of the Properties of High-strength Concrete Subjected to Elevated Temperatures.

14) Pimienta, P., Alonso, M.C., McNamee, R.J., and Mindeguia, J.C. (2017). Behaviour of high-performance concrete at high temperatures: some highlights. RILEM Technical Letter, 2, p. 45-52.

15) Novak, J., and Kohoutkova, A. (2017). Fibre reinforced concrete exposed to elevated temperature. IOP Conf. Ser.: Mater. Sci. Eng. 246 012045.

16) Tsai, C-T., Li, L-S., Chang, C-C., and Hwang, C-L. (2009). Durability design and application of Steel Fiber Reinforced Concrete in Taiwan. The Arabian Journal For Science & Engineering Vol-34, pp 57-79.

17) Norhayani, M.N., Kamariah, M.P., and M. Ziunizan, H. Civil Engineering Laboratory Manual, International Circulation For Faculty of Civil Engineering & Earth Resources. 3rd edition. Universiti Malaysia Pahang (UMP), pp. 12-36.

18) Maca, P., Sovjak, R., and Vavrinik, T. (2013). Experimental Investigation of Mechanical Properties of Ultra High Performance Fiber Reinforced Concrete (UHPFRC). Procedia Engineering 65, p. 14-19.

19) Colombo, M., Prisco, D., and Felicetti, R. (2010). Mechanical Properties of Steel Fiber Reinforced Concrete Exposed at High Temperatures. Mater structure, 43(4): 475-91.

20) Aggeliki, K. and Stonecypher, L. (2011). Steel Fiber Reinforced Concrete. [online] Bright Hub Engineering. Available at: https://www.brighthubengineering.com/concrete-technology/52076-steel-fiber-reinforced-concrete/ [Accessed 2 Nov, 2011].

21) Chen et al. (2012). Effect of moisture content on compressive and split tensile strength of concrete. Indian Journal of Engineering & Materials Sciences. Vol. 19, December 2012, pp. 427-435.

**APPENDIX A**
**SAMPLE APPENDIX 1**


Figure 1.1: Weight aggregates size 10 mm


Figure 1.2: Weight aggregate size 20 mm

Figure 1.3: Prepared for sieve size sand

Figure 1.4: Prepared samples of concrete mix

Figure 1.5: Separate the steel fibers


Figure 1.6: Weight the steel fibers


Figure 1.7: Samples of cube size 150 mm

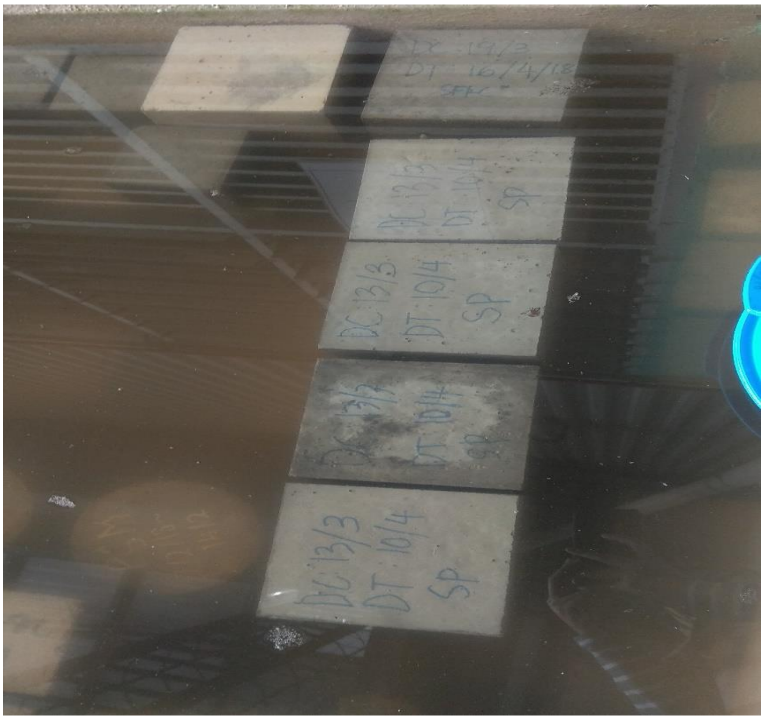


Figure 1.8: Curing process

**APPENDIX B**
**SAMPLE APPENDIX 2**

Figure 2.1: Compressive strength test

Figure 2.2: Samples after the compressive test