ENGINEERING PROPERTIES OF LIGHTWEIGHT FOAMED CONCRETE WITH 7.5 % EGGSHELL AS PARTIAL CEMENT REPLACEMENT MATERIAL

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Civil Engineering

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April 2015

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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Specially dedicated to

my beloved late grandfather, father and mother

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ABSTRACT

Eggshell is a common waste product generated in our daily life but not a common useable material in any industries. Due to the high content of calcium carbonate contained in eggshell, it has raised the awareness of researchers of incorporating it in production of lightweight foamed concrete (LFC) while contributing to reduction of waste disposal problem at the same time. Therefore, the objective of this experimental study is to investigate the effect of eggshell powder as partial cement replacement material on engineering properties of LFC with density of 1300 kg/m^3 in terms of compressive, splitting tensile and flexural strengths, Poisson's ratio as well as compressive toughness. Two types of lightweight foamed concrete were prepared for this study, namely i) LFC with 100 % pure cement as control mix (LFC-CTR) and ii) LFC with 7.5 % of eggshell as partial cement replacement material (LFC-ES7.5). Fresh properties namely workability, fresh density, stability and consistency of the concrete were determined during the trial mixes. Optimal water to cement ratio was obtained by casting trial mixes with different water to cement ratios ranging from 0.52 to 0.60, with interval of 0.04. The optimal water to cement ratio was then used to study the development of engineering properties for 7, 28, 56, 90 and 180 days of ages between LFC-CTR and LFC-ES7.5. All the concrete samples were water cured for the desired period before being tested. The laboratory results showed that the incorporation of eggshell powder into lightweight foamed concrete has increased its compressive, splitting tensile and flexural strengths, Poisson's ratio as well as compressive toughness. Besides that, it was found that the microstructure of LFC was denser and the pore sizes of the concrete structure are smaller with the incorporation of eggshell as compared with that of control mix.

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LIST OF SYMBOLS / ABBREVIATIONS

A	Area, m^2
b	Width of specimen, mm
d	Diameter of specimen, mm
ε	strain, 10^{-6} mm/mm
ε_f	strain upon failure, 10^{-6} mm/mm
E	Chord modulus of elasticity, MPa
f	Compressive strength, MPa
l	Length of specimen, mm
P	Maximum load carried by specimen, N
PI	Performance index, MPa per 1000 kg/m^3
R	Flexural strength, MPa
S_1	Stress corresponding to a 50 millionths, MPa
S_2	Stress corresponding to 40 % of ultimate load
T	Splitting tensile strength, MPa
μ	Poisson's ratio
μ_t	toughness, J/m^3

ASTM	American Society for Testing and Materials
C-S-H	Calcium Silicate Hydrate
EDS	Energy-dispersive X-Ray Spectroscopy
ESP	Eggshell powder
LFC	Lightweight foamed concrete
LFC-CTR	Control mix (Lightweight foamed concrete with 100 % cement)
LFC-ES7.5	Lightweight foamed concrete with 7.5 % of eggshell as partial cement replacement material
OPC	Ordinary Portland Cement
SEM	Scanning Electron Microscope
w/c	Water to cement ratio

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Concrete is one of the most widely used building materials in the construction world due to its engineering characteristics and properties. It is a composite construction material that composed of cement, aggregate, sand and water. It is said to be a sustainable material when constructed with proper design. Nowadays, there are many types of concrete being produced as to fulfil the demand of the construction world. As innovation never ends, a lot of development and enhancement to the concrete have been done as to produce more superior concrete and the improvement still ongoing.

One of the concrete which known as lightweight foamed concrete has gained its popularity and being widely used in civil engineering industry due to the advantages it possesses. Lightweight foamed concrete possesses a low density varies in range between 300 kg/m^3 to 1850 kg/m^3 as compared to normal weight concrete which usually range between 2200 kg/m^3 and 2600 kg/m^3 of density (Neville, 2010). Besides that, its versatilities and lightness helps in reducing the dead load imposed on concrete structure and subsequently lead to reduction in size of columns and other load bearing structure elements. Consequently, reduction in size of load bearing structure elements required less reinforcement and thus resulting in more economical design. Apart from that, lightweight foamed concrete also provides better fire resistance and thermal insulation properties.

As concrete being widely used for the construction, a lot of researches and studies have been carried out of producing better concrete from blended cement which consists of industrial or agricultural waste as partial replacement of cement content. The researches for the application of industrial and agricultural waste such as palm oil fuel ash, timber industrial ash and rice husk ash have gained much attention recently. For this experimental study, eggshell has been chosen as the material to replace 7.5 % of cement used in lightweight foamed concrete.

Eggshell can be easily obtained from the wastes generated in our daily life and it can be found in bulk amounts from bakeries and restaurants. By reusing the eggshell waste not only can help in reducing wastes but also saving the landfill area and minimize pollution to the environment. There are several studies regarding mixing eggshell powder with cement have been done in the past. For instance, a study on concrete regarding using fly ash, rice husk ash and egg shell powder had been carried out by some researchers. Several sets of concrete specimen were casted with different proportion of ash, rice husk ash and egg shell powder and compressive strength of each of the specimens was obtained. It showed that the compressive strength is decreased when higher percentage of cement is replaced by eggshell powder (Jayasankar *et al*., 2010). Other researches on application of eggshell which have been done includes the experimental analysis on suitability of eggshell stabilized lateritic soil as subgrade material for road construction (Olarewaju *et al*., 2011), the effect of eggshell ash on strength properties of cement-stabilized lateritic (Okonkwo *et al*., 2012) and so on.

1.2 Problem Statement

Nowadays, concrete plays an important role in construction industry. However, the high cost of concrete has caused the building construction to be less economical. In order to solve this problem, lightweight foamed concrete has been utilized for some of the building structural components. Lightweight foamed concrete comes with low density which can help in reducing the dead load imposed on structure corresponding with cost saver on smaller foundation requires. It can help in reducing reinforcement used in building structure and thus results in a more economical design.

Besides that, more than 40 million eggs are produced in Malaysia's industry every day. According to Malaysia Veterinary Department (DVS), the consumption of eggs in year 2012 is 9354 million eggs with an increasing trend of about 400 million per year. It is estimated that consumption of eggs had reached 9403 million eggs in year 2013. Average weight of eggshell is estimated to be 5 g. The disposal of eggshell will be equates to about 47000 tonnes of eggshell wastes to be dumped and it will cause a serious environmental problem (DVS, 2013). Therefore, a study regarding eggshell as part of cement replacement material has been carried out to help in reducing the eggshell wastes as well as minimizing the pollution to environment.

1.3 Objectives of Study

The objectives of this study are:

1. To produce lightweight foamed concrete with density in the range of 1250 – 1350 kg/m^3.
2. To obtain optimal water to cement ratio for
    i. Lightweight foamed concrete with 100 % pure cement as control mix (LFC-CTR), and
    ii. Lightweight foamed concrete with 7.5 % of eggshell as partial cement replacement material (LFC-ES7.5).
3. To assess the effect of eggshell on fresh properties of lightweight foamed concrete in terms of workability, consistency and stability.
4. To study the effects of eggshell as part of cement replacement material on engineering properties of lightweight foamed concrete in terms of compressive, splitting tensile and flexural strengths, Poisson's ratio as well as compressive toughness.

1.4 Scope of Study

This study is to determine the effects of 7.5% of cement content replaced by eggshell powder on engineering properties of lightweight foamed concrete in terms of compressive, splitting tensile and flexural strengths, Poisson's ratio as well as compressive toughness. The targeted density of lightweight foamed concrete for this experimental study is 1300 kg/m^3 with tolerance of ± 50 kg/m^3. Two types of lightweight foamed concrete were casted, namely i) Lightweight foamed concrete with 100 % pure OPC cement as control mix (LFC-CTR) and ii) Lightweight foamed concrete with 7.5 % of eggshell as partial cement replacement material (LFC-ES7.5). The optimal water to cement ratio for LFC-CTR and LFC-ES7.5 were determined by casting concrete samples using different water to cement ratios ranging from 0.52 to 0.60, with an interval of 0.04. During trial mixes stage, inverted slump test and compressive strength test were carried out to determine the optimal water to cement ratio for each of the mix proportion. The concrete cube specimens were cured in water tank for 7 days and 28 days before carrying out the compressive strength testing. Inverted slump test was carried out to determine the workability of fresh concrete. Performance index of lightweight foamed concrete for each of the mix proportion was then calculated based on the compressive strength and hardened density of concrete cube specimens.

Finally, the optimal water to cement ratio that has been determined was used to cast further concrete specimens. The concrete specimens including cubes, cylinders and prisms were cured in water and tested for 7, 28, 56, 90 and 180 days compressive, splitting tensile and flexural strengths. For Poisson's ratio test, cylinders were cured in water for 90 days before conducting testing. Besides that, for lightweight foamed concrete at 90 and 180 days of ages, small crushed piece of concrete specimen were used for the microstructural studies using Scanning Electron Microscope (SEM) and Energy-dispersive X-Ray Spectroscopy (EDS). The results of LFC-CTR and LFC-ES7.5 were then studied and discussed.

1.5 Significance of Study

The significances of this study are:

1. Incorporating eggshell as part of cement replacement material in the mixing process as to create a more sustainable environment and an innovative recycled material industry besides enhancing the strength of concrete.
2. Developing the mix proportions and study the engineering properties of lightweight foamed concrete incorporated with eggshell in terms of compressive, splitting tensile and flexural strengths, Poisson's ratio as well as compressive toughness.

1.6 Layout of Report

This report consists of 6 chapters. Chapter 1 discusses the introduction of the study, problem statement of the study, objectives of the study, scopes of study, significance of study and layout of report.

Chapter 2 discusses the review on the properties of lightweight foamed concrete and regarding the supplementary cementing material. This includes all materials used such as cement, aggregate, eggshell and foam based on some professional's studies, articles, research paper, and etc.

Chapter 3 is about the methodology used in this study. This includes the method of getting the mix proportion, the preparation of materials, mixing procedure and test methods involved.

Chapter 4 is mainly discusses the results of trial mixes. The optimal water to cement ratio for LFC-CTR and LFC-ES7.5 were determined based on the results of trial mixes, respectively.

Chapter 5 is mainly discusses the laboratory results of lightweight foamed concrete with eggshell as partial cement replacement material in terms of compressive, splitting tensile and flexural strengths, Poisson’s ratio as well as compressive toughness.

Chapter 6 summarizes and concludes the study based on the results obtained. Few conclusions are made respectively according to the objectives of this experimental study. Other than that, recommendations are also given in this chapter for further improvement and development.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Lightweight foamed concrete is a type of concrete made up of a mixture of raw materials such as ordinary Portland cement, fine aggregate, water and other suitable forming agent which help in entrapping air bubbles inside the cement paste. As compared to normal weight concrete, lightweight foamed concrete possesses a better lightness, controlled low strength, excellent sound and thermal insulation (Ramamurthy *et al*., 2009).

Throughout the years, lightweight foamed concrete with a wide range of densities ranged from 400 kg/m^3 to 1600 kg/m^3 had been used for structural and construction purpose. A production of stable foamed concrete mix depends on many factors such as selection of type of foaming agent, method of foam preparation, addition of foam into concrete mix for uniform air-voids distribution, production of foamed concrete and performance of concrete in respect to its fresh and hardened state are of greater significance (Ramamurthy *et al*., 2009).

Incorporation of eggshell waste in field of civil engineering was studied by some researchers in their research papers. For instance, characterization of avian eggshell waste which used in a ceramic wall tile paste (Freire *et al*., 2006), incorporation of eggshell into expansive clay soil to study its effect on the stabilizing potential of lime (Amu *et al*., 2005) and eggshell as subgrade material for road construction (Olarewaju *et al*., 2011).

2.2 Advantages of Lightweight Foamed Concrete

Lightweight foamed concrete had achieved a better results in some properties make it more favourable than normal weight concrete. Even though lightweight foamed concrete possesses a comparatively lower compressive strength than normal weight concrete due to its low density, the performance of lightweight foamed concrete as a non-load bearing components has decreased the structural dead load substantially, help in reducing size of columns and other load bearing structural elements and lead to a lower construction cost. Other than that, high workability and flowability of lightweight foamed concrete can help to ease the casting and transportation job, which helped in saving a lot of time. Besides that, due to the high porous structure of lightweight foamed concrete, it can achieve good thermal insulation properties than normal weight concrete (Kim *et al*., 2011). With this, the building can maintained at a relatively lower temperature compared to outdoor temperature, since lightweight foamed concrete helped to prevent hot temperature from penetrating into the building structure. Apart from that, lightweight foamed concrete also promote other advantages such as good fire resistance, acoustical properties and self-compaction properties (Kim *et al*., 2011).

2.2.1 Compressive Strength

The compressive strength of concrete is a most common and important engineering properties for concrete, including lightweight foamed concrete. According to research studied by Kearsley (1996), the compressive strength of concrete will reduce exponentially in corresponding to the adding of foam into concrete to reduce its density (Kearsley, 1996). Other than concrete density, compressive strength of concrete will also influenced by other external factors such as shape and size of specimen, method of pore formation, direction of loading, curing period, water content, characteristics of ingredients used and the method of curing (Valore, 1954). Other than that, the compressive strength of concrete will affected by other factors such as the cement-sand and water cement ratios, type and particle size distribution of sand, curing regime and not to mention the type of foaming agent used (Aldridge, 2005; Hamidah *et al*., 2005).

2.2.2 Splitting Tensile Strength

For splitting tensile strength of lightweight foamed concrete, it is one of the basic and important properties of concrete even though concrete is usually not expected to resist tension due to its low tensile strength and brittle nature. However, determination of tensile strength of concrete is necessary to determine the load at concrete members may fails. It is tends to be lower than compressive strength due to its developments of quicker crack propagation. The splitting tensile strength is assumed to be proportional to the square root of compressive strength (Choi & Yuan, 2005). Besides that, the splitting tensile strength of lightweight foamed concrete is expected to be lower than normal weight concrete (Ramamurthy *et al*., 2009).

2.2.3 Flexural Strength

For the flexural strength of lightweight foamed concrete, the ratio of flexural strength to compressive strength of lightweight foamed concrete is lie between the range of 0.25 – 0.35 (Ramamurthy *et al*., 2009).

2.3 Foam

Concrete that mixed together with foam possesses high flow ability, low self-weight, minimal consumption of aggregate, controlled low strength and excellent thermal insulation properties. Furthermore, it has excellent resistance to water and frost and provides high level of sound insulation (Kim *et al*., 2011).

There are two methods to produce foamed concrete, which categorized into pre-foaming method and after-foaming method (Ramamurthy *et al*., 2009). Pre-foaming method comprises of producing base mix and stable preformed aqueous foam separately and then blending the foam into the base mix (Byun *et al*., 1998). Before blending the foam into the base mix, it must be ensured that the foam produced is firm and stable so that it can resists the pressure of mortar until the cement takes its initial set and a strong skeleton of concrete is built up around the void filled with air (Koudriashoff, 1949). If the foam is not stable, the pressure within the mortal might easily burst up the air bubbles when it is mixed into the mortar. Extra foam is needed to add in to achieve the desired density which is not preferable.

There are two types of pre-foamed foam, which are wet foam and dry foam. According to Aldridge (2005), by forcing the foaming agent through a series of high density restrictions, at the same time introduce the compressed air into the same mixing chamber, dry foam which is smaller than 1 mm will be produced. The foam is made up by using a foam generator. First, the concentrated foaming agent is diluted in water to produce a pre-foaming solution and then the solution is poured into foam generator to expand with air into dry foam. The size of dry foam is smaller than 1 mm. The small size of foam is easier to mix uniformly with other base materials for producing a pump able foamed concrete. For wet foam, the bubble size is larger as compared to dry foam which is 2 mm to 5 mm. It is formed by spraying foaming agent solution over a fine mesh. However, the foam produced relatively less stable compared to dry foam (Aldridge, 2005).

For after-foaming type foamed concrete, the foaming agent which is the surface active agent is then added into the cement mix during the mixing process. The foam is produced resulting in cellular structure in concrete (Byun *et al*., 1998).

2.4 Ordinary Portland Cement

In accordance with ASTM C150 (2005), ordinary Portland cement (OPC) is classified as Type I cement. The ordinary Portland cement is one of the most common types of cement which used in the construction field nowadays. It is suitable for general construction when there is no exposure to sulphates in soil or groundwater (Neville, 2010).

2.4.1 Chemical Composition of Portland Cement

The chemical compositions of Portland cement are slightly varying according to cement supply of manufacturers. However, it mostly contained limestone, alumina and silica as these few types of chemical compound are extremely vital for the formation of calcium silicate hydration during hydration process. A general idea on range of chemical composition of OPC is listed in Table 2.1 (Neville, 2010).

Table 2.1: General Composition Limits of Portland Cement (Neville, 2010)

Oxide	Content, %
CaO	60 – 67
SiO_2	17 – 25
Al_2O_3	3 – 8
Fe_2O_3	0.5 – 6.0
MgO	0.5 – 4.0
Na_2O	0.3 – 1.2
SO_3	2.0 – 3.5

2.4.2 Compound Composition of Portland Cement

The four raw materials that used in Portland cement manufacturing mainly are lime, silica, alumina and iron oxide. The reactions were carried out in the rotary kiln and form complex chemical compound. The complex chemical compounds that formed in the rotary kiln were referred to the major constituents of cement and these compounds are listed in Table 2.2 (Neville, 2010).

Table 2.2: Main Compounds of Portland Cement (Neville, 2011)

Name of Compound	Oxide Composition	Abbreviation	Compound Composition (%)
Tricalcium Silicate	$3CaO.SiO_2$	C_3S	42 – 67
Dicalcium Silicate	$2CaO.SiO_2$	C_2S	8 – 31
Tricalcium Aluminate	$3CaO.Al_2O_3$	C_3A	5 – 14
Tetracalcium Aluminoferrite	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF	6 – 12

2.5 Eggshell

As mentioned in Chapter 1, eggshell has been a waste disposal which creates pollution to environment. According to Malaysia Veterinary Department (DVS), the consumption of egg in year 2012 had reached 9354 million eggs and it is estimated to reach 9403 million eggs in year 2013. This large amount of egg supply are equate to about 47000 tonnes of eggshell wastes to be disposed every year and eventually lead to serious environmental issue (DVS, 2013).

As the demand of consumers on eggs increasing year by year, allocation of landfills for eggshell wastes disposal is no longer an effective solution to manage the waste. Due to this waste disposal problem, there are more and more researchers aware about this waste material. Therefore, several researches had been studied to solve the eggshell waste problem by allocating eggshell waste into certain field especially civil engineering field. Researches that conducted by Okonkwo *et al*. (2012), Freire *et al*. (2006), Jayasankar *et al*. (2010) and Olarewaju *et al*. (2011) had proved that eggshell can be incorporated into concrete and increase the strength properties of concrete for construction purpose.

2.5.1 Chemical Properties of Eggshell

According to the researches of Freire and Holanda (2006), calcium oxide was the main composition of the eggshell, stands up to 50.7 % of eggshell chemical composition. Eggshell contained of other minor chemical composition such as silicon dioxide, aluminium (II) oxide, magnesium oxide, ferric (II) oxide, sodium oxide, phosphorus oxide, strontium oxide, nickel oxide, sulphur oxide and chlorine. The total amount of these chemical compounds just composed of 1.361 % of eggshell (Freire *et al*., 2006). The chemical compositions of eggshell in the form of percentage are listed in Table 2.3.

Table 2.3: The Chemical Composition of Eggshell (Freire *et al*., 2006)

Chemical Composition	Content
Calcium oxide (CaO)	50.70
Silicon dioxide (SiO_2)	0.09
Aluminum oxide (Al_2O_3)	0.03
Ferric oxide (Fe_2O_3)	0.02
Magnesium oxide (MgO)	0.01
Sodium oxide (Na_2O)	0.19
Strontium oxide (SrO)	0.13
Nickel oxide (NiO)	0.001
Phosphorus oxide (P_2O_5)	0.24
Sulphur oxide (SO_3)	0.57
Chlorine (Cl)	0.08
Loss of ignition (LOI)	47.8

*All values are in percentage

However, there are other research stated that calcium carbonate was the main composition of by-product eggshell, which stands up to 94 %. According to Tsai et al.'s 2006 study (as cited in Stadelman, 2000), the other minor chemical composition of eggshell are magnesium carbonate, calcium phosphate and organic matter. The calcium carbonate can act as inert filler which enhance the space-filling properties of paste which possible leading to the reduction of porosity and permeability of hardened cement paste (Matschei *et al*., 2006). The chemical compositions of eggshell in the form of percentage are listed in Table 2.4.

Table 2.4: The Chemical Composition of Eggshell (Stadelman, 2000)

Chemical Composition	Content
Calcium carbonate ($CaCO_3$)	94.0
Magnesium carbonate ($MgCO_3$)	1.0
Calcium phosphate	1.0
Organic matter	4.0

*All values are in percentage

2.5.2 Effect of Particles' Fineness on Concrete Strength

Theoretically, finer size of materials will help in increasing the strength of concrete due to the exposed of larger total surface area of material that providing more bonding surface between particles. The reaction effect on concrete strength also tends to be higher by using the finer size of materials. Based on the research studies on fineness of palm oil fuel ash (POFA) by Awal (1998), it can be concluded that finer material will lead to higher strength of concrete, as shown in Figure 2.1 (Awal, 1998). Hence, a particular assumption can be made towards the fineness of the eggshell powder against its reaction effect, the finer the eggshell powder, the higher the reaction effect on concrete strength.

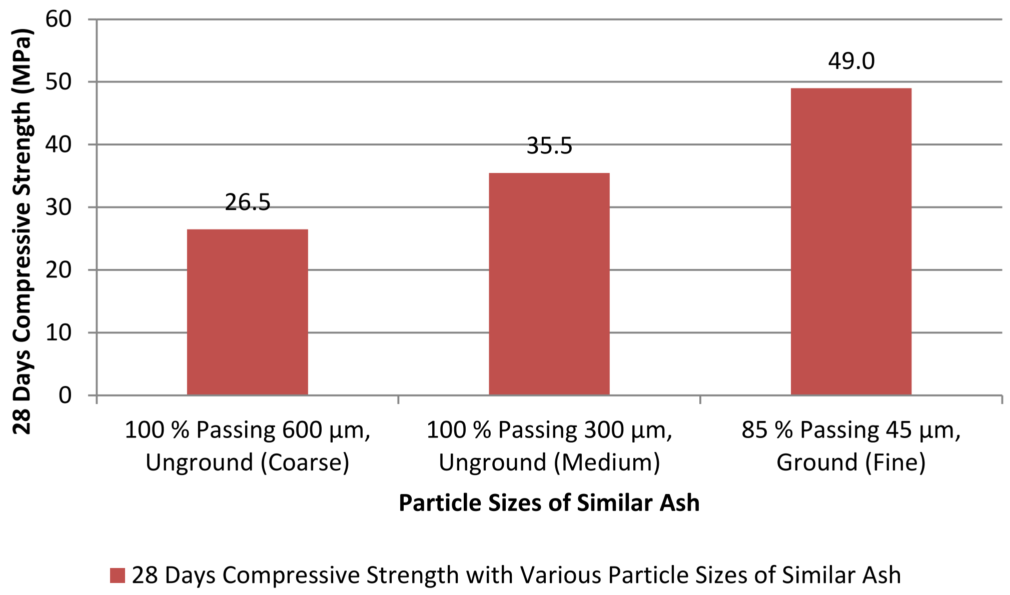

Figure 2.1: Fineness of POFA on Concrete Strength (Awal, 1998)

2.5.3 Eggshell in Normal Weight Concrete

According to Jayasankar et al. (2010), a study of compressive strength of fly ash (FA), rice husk ash (RHA) and eggshell powder (ESP) that added into normal weight concrete was carried out. The purpose of this research is to study the effect of concrete with 5 %, 10 %, 15 % and 20 % of FA, RHA and ESP as partial cement replacement material. Three types of concrete, which are M20, M25 and M30 grade concrete were casted to obtain the 14 days compressive strength after added in with different admixtures. Based on the research, that certain range of eggshell powder percentage that added into concrete will achieve compressive strength that higher than or 90 % of designed strength (Jayasankar *et al*., 2010). The results of eggshell powder with different grade of normal weight concrete on compressive strength were extracted out, concluded and illustrated in Figure 2.2.

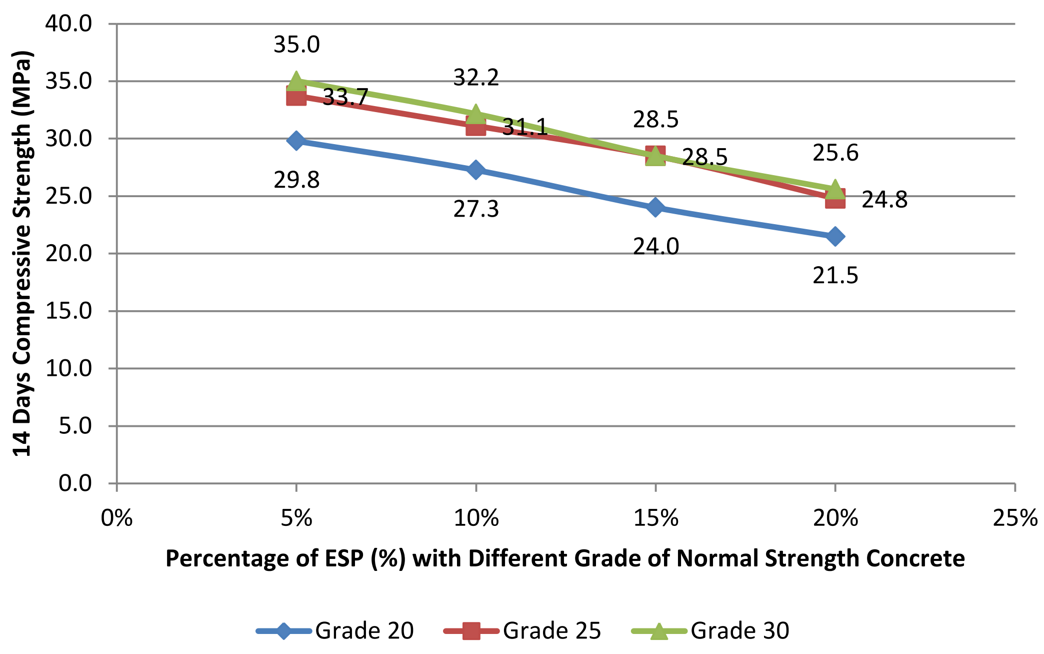

Figure 2.2: Compressive Strength for Various % Eggshell Powder (ESP) in Different Designed Strength (Jayasankar *et al.*, 2010)

The results for compressive strength of normal weight concrete were shown in Figure 2.2 for concrete grade 20, grade 25 and grade 30. Based on the studies on normal weight concrete with ESP as cement replacement, as the designed strength goes higher, the compressive strength with 20 % of eggshell powder as partial cement replacement material is less than 90 %. Besides that, it also showed that the 14 days compressive strength of normal weight concrete is decreasing with the increasing in ESP percentage as partial cement replacement material. Therefore, another assumption can be made that ESP has its properties and effect in boosting compressive strength of concrete, but it only limited to certain amount of replacement.

2.6 Summary

Lightweight foamed concrete is a mixture of cement, fine aggregates, water and foam which produce air bubbles and entrapped inside fresh concrete. The foam can either be produced by pre-foaming method or after-foaming method. It can either be wet foam or dry foam. The lightweight foamed concrete possesses a lot valuable advantages in practice, such as reducing dead load of structure, good thermal insulation, sound insulation, fire resistance and acoustical properties as well as easy in casting, placing and transporting process.

Even though eggshell does not contain any siliceous pozzolanic characteristics which used in increasing strength of concrete, its high percentage of calcium carbonate content becomes its superiority to be part of the supplementary cementing materials for concrete. Eggshell is added to assess its effect on the strength and durability of the concrete in terms of compressive, splitting tensile and flexural strengths.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the materials used, mixing procedure and test methods that will be carried out in conducting the experimental study. The collection and preparation of materials, mixing procedure and every test methods for lightweight foamed concrete with 7.5 % of eggshell as cement replacement are presented in details in this chapter.

3.2 Raw Materials Used

The material used in producing lightweight foamed concrete with 7.5 % of eggshell as cement replacement consists of five types of raw materials, which are ordinary Portland cement, eggshell, fine aggregate, water and foam.

3.2.1 Ordinary Portland Cement (OPC)

Ordinary Portland Cement (OPC) of "ORANG KUAT" which manufactured by YTL Cement Sdn. Bhd. as shown in Figure 3.1 was used throughout this experimental study. The cement used is categorized as Type I Portland cement in accordance with ASTM C150 (2005). For this study, the OPC was sieved through 300 μm sieve with 100 % passing rate in order to remove the clinker of hydrated cement particle. The sieved OPC was placed inside the airtight container to prevent air moisture come in contact with the OPC as shown in Figure 3.2 since it would be easily hydrated and affect the formation of Calcium Silicate Hydrate gel. The details chemical composition of OPC is stated in Table 3.1.

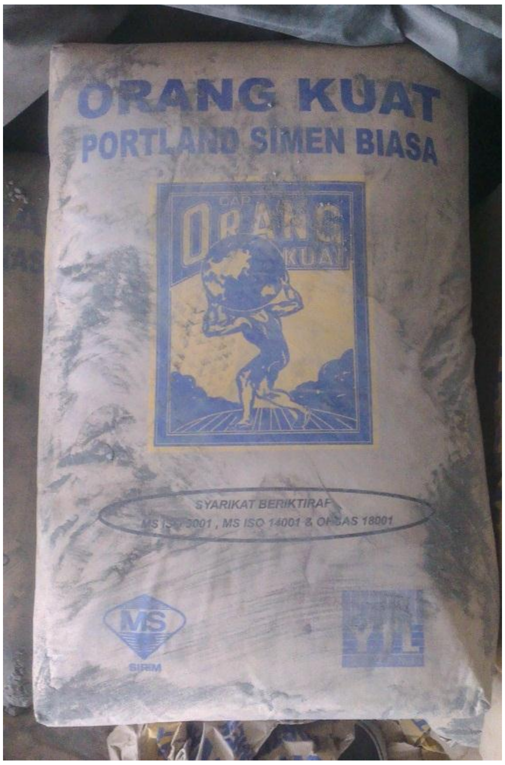

Figure 3.1: "ORANG KUAT" Branded Ordinary Portland Cement (OPC)

Figure 3.2: Sieved Ordinary Portland Cement (OPC)

Table 3.1: Chemical Composition of OPC (SGS Analysis Report, 2007)

Chemical Composition	OPC
Silicon dioxide (SiO_2)	20.10
Aluminium oxide (Al_2O_3)	4.90
Ferric oxide (Fe_2O_3)	2.50
Calcium oxide (CaO)	65.00
Magnesium oxide (MgO)	3.10
Sulphur oxide (SO_3)	2.30
Sodium oxide (Na_2O)	0.20
Potassium oxide (K_2O)	0.40
Titanium oxide (TiO_2)	0.20
Phosphorus oxide (P_2O_2)	<0.90
Loss of ignition (LOI)	2.40

*All values are in percentage

3.2.2 Eggshell

Chicken eggshell waste used in this study was collected from the culinary business and hawker centre at nearby area. The collected eggshell was rinsed and cleaned with tap water to remove the residue of eggshell. Next, the eggshell was placed for air dry under normal condition, as shown in Figure 3.3. After that, the eggshell was crushed manually and ground into powder form by using blender that shown in Figure 3.4. The ground eggshell powder was sieve through 63 μm sieve. The size is approximately same as that of cement particle, which is 45 μm.

Figure 3.3: The eggshells are being dried under outdoor natural condition

Figure 3.4: Blender

3.2.3 Fine Aggregate

In this experimental study, only fine aggregate was used in producing the lightweight foamed concrete with 7.5 % of eggshell as cement replacement. According to ASTM C778 (2002), the fine aggregate used for concrete mix has to pass through the 600 μm sieve. Before that, the fine aggregate was dried in an oven at the temperature of 105 ℃ ± 5 ℃ for at least 24 hours to get rid of the water content in fine aggregates. As similar to OPC, the sieved fine aggregate was kept in a container to prevent the moisture contacts with the fine aggregate, whereas the moisture content will affect water to cement ratio of concrete casting. Figure 3.5 shows the oven dry process of fine aggregates.

Figure 3.5: Fine aggregates are being oven dried

3.2.4 Water

Water is one of the main materials to produce lightweight foamed concrete. As complied with ASTM C1602 (2006), concrete casting can use combined water, mixing water, non-potable water and portable water as mixing water. The water that used for concrete casting should not have any harmful impurities that will affect the hydration process of cement and durability of concrete in long term. In this experimental study, tap water was used as the mixing water to cast the lightweight foamed concrete.

3.2.5 Foam

The lightweight foamed concrete that produced in this study was controlled at density of 1300 kg/m^3 with tolerance of $\pm$50 kg/m^3. Foam has been used to control the density of lightweight foamed concrete by adding the dry performed stable foam into the fresh lightweight foamed concrete mix. They were mixed thoroughly until the desired density was achieved. For this study, pre-foamed method was adopted to produce foam by using a foam generator. Figure 3.6 shows the foam generator used in the laboratory. The ratio of foaming agent to water is 1:30 by volume and the foam generator was operated under the pressure of 0.5 MPa. The foam produced had a density of 45 ± 5 kg/m^3. Figure 3.7 shows the foam that produced and has been added into fresh cement mortar mixture.

Figure 3.6: Foam Generator

Figure 3.7: Foam produced that added into fresh cement mortar mixture

3.3 Mould

In this study, various types of mould are needed for concrete casting. Three types of mould were used for concrete specimens casting namely cubic, cylindrical and prismatic specimens. By following the requirement of ASTM and BS code, the cubic mould with the dimension of 100 mm x 100 mm x 100 mm is used for compressive strength test; cylindrical mould with diameter of 100 mm and height of 200 mm is used for splitting tensile strength test and Poisson's ratio test; and lastly the prismatic mould with dimension of 25 mm x 25 mm x 250 mm is used for flexural strength test. Before pouring the fresh concrete into the mould, it needs to be tightened, cleaned up and applied a thin layer of oil to ease the demoulding job after the concrete is hardened. The cubic mould, cylindrical mould and prismatic mould are showed in Figures 3.8, 3.9 and 3.10 respectively.

Figure 3.8: Cubic Mould

Figure 3.9: Cylindrical Mould

Figure 3.10: Prismatic Mould

3.4 Trial Mix

In this trial mix stage, two types of mix proportion were adopted, which are lightweight foamed concrete with 100 % of fine aggregate as filler (LFC-CTR) and 7.5 % of eggshell as partial cement replacement material (LFC-ES7.5). The purpose of trial mix was to determine the optimal water to cement ratio for both of the mix proportion based on the 7 days and 28 days compressive strength test results. The water to cement ratio used for each type of mix proportion is ranged from 0.52 to 0.60, with the interval of 0.04. The density of concrete mix was controlled at 1300 kg/m^3 with tolerance of ± 50 kg/m^3.

3.5 Mixing Procedure

In this study, the OPC, fine aggregates and eggshell powders were weighted and pour into a stainless steel mixing pot for mixing until evenly mixed. After that, water was weighted and added into the dry mix. The wet mix was mixed manually until it was uniformly mixed. At the same time, foam was generated by the foam generator. Before adding foam into the wet mix, the fresh density of cement mortar was measured by using a 1 litre container and flow table spread test was carried out. Then, foam was weighted and added into the wet mix. The foam was added until the desired density of 1300 kg/m^3 ± 50 kg/m^3 was achieved. Lastly, inverted slump test was carried out, followed by pouring the fresh concrete mix into the mould that had been prepared earlier.

3.6 Curing

Water curing is a vital process for cement concrete to gain strength. For this experimental study, the hardened concrete specimens were cured in the water tank for 7, 28, 56, 90 and 180 days of ages until the testing age. The water temperature was in the range of 25 - 30 ℃. All the concrete specimens need to be fully immersed into water. Figure 3.11 shows the water curing process of concrete specimens.

Figure 3.11: Water Curing

3.7 Fresh Concrete Testing Method

During the fresh concrete mixing, several tests namely fresh density test, flow table spread test and inverted slump test were carried out before pouring the fresh concrete into mould. The tests were conducted to determine the fresh properties of the concrete mix.

3.7.1 Fresh Density Test (ASTM C796, 2004)

The fresh density test was carried out in accordance with ASTM C796 (2004). A 1 litre capacity of container was prepared for the test. Firstly, the container was tarred to zero at weighting machine before filling up with fresh concrete mix. The container was then filled in with fresh lightweight foamed concrete and excess lightweight foamed concrete was struck off to ensure the surface was flat. Besides that, the container was slightly shaken to allow the fresh lightweight foamed concrete to fill up the empty space in the container. Then, the container which fully contained of fresh lightweight foamed concrete was weighted on the weighting machine to obtain its fresh density. The measurement was repeated before and after the foam was added. Figure 3.12 shows the measurement of fresh concrete density using a 1 litre capacity of container.

Figure 3.12: Fresh density of lightweight foamed concrete is being measured

3.7.2 Flow Table Spread Test (ASTM C230, 2003)

According to ASTM C230 (2003), the flow table spread test was conducted to determine the consistency and flow ability of fresh concrete. It was carried out before foam was added. The conical mould must place at the centre of the flat circular shield. The fresh concrete was then poured into the conical mould; subsequently the overfilled concrete was struck off to ensure the surface was flat. After that, the conical mould was removed. The fresh concrete was allowed to spread on the circular shield and number of drops was recorded. Figure 3.13 shows the round plate and conical mould that used for flow table spread test while Figure 3.14 shows the fresh concrete mixture that spreading over the round plate.

Figure 3.13: Round plate and conical mould used for flow table spread test

Figure 3.14: The fresh concrete mixture spreading over the round plate

3.7.3 Inverted Slump Test (ASTM C1611, 2005)

As complied with ASTM C1611 (2005), the inverted slump test was carried out throughout the study by using a slump cone and flat base tray. The slump cone was inverted and place at the centre of the flat base tray, it was filled up with fresh lightweight foamed concrete. The overfilled fresh lightweight foamed concrete was struck off to ensure a flat top surface. After that, the inverted slump cone was then lifted to 1 ft height. The diameters of circular spread of fresh concrete from four different angles were measured and recorded. If a halo is observed in the circular spread of fresh concrete, second diameter need to be measured as stated in ASTM C1611 (2005). Figure 3.15 shows the inverted slump cone with flat base tray while Figure 3.16 shows the inverted slump test.

Figure 3.15: Inverted Slump Cone with Flat Base Tray

Figure 3.16: Inverted Slump Test

3.8 Hardened Concrete Testing Method

There are various methods that can be used to determine hardened concrete properties, which mainly categorized as destructive and non-destructive test. For this experimental study, destructive test was adopted. All the destructive tests were performed under INSTRON 5582 Testing Machine. All the hardened concrete specimens were taken out one day in advanced from the water tank and oven dried for 24 hours before the destructive test.

3.8.1 Compressive Strength Test (BS EN 12390-3, 2002)

As complied with BS EN 12390-3 (2002), the compressive strength test was conducted by using INSTON 5582 Testing Machine. An axial compression load with constant loading rate of 0.02 mm/s was applied on the concrete cubic specimens with dimension of 100 mm x 100 mm x 100 mm until failure occurred. The compressive strength test for LFCs were done in triplicate, but only the average values were reported in this study.

The concrete cubic specimens were oven-dried for 24 hours before the compressive strength test was carried out. Flat surface of concrete specimen was chosen as the surface for compression load application. The dimension of concrete cubic specimen was measured using digital vernier caliper to determine the cross-sectional area before the testing, as shown in Figure 3.17. Then, the test specimen was located at the centre of the testing machine and loaded with the specified rate of loading until the test specimen fail and cracks appeared on the specimen's surface, as shown in Figure 3.18. The maximum load sustained by the specimen was recorded and used for calculation of compressive strength. Compressive strength of concrete cubic specimen is calculated using Equation 3.1.

$$\mathrm{f} = \frac{\mathrm{P}}{\mathrm{A}} \tag{3.1}$$

where

f = compressive strength, MPa

P = maximum load sustained by specimen, N

A = cross-sectional area of specimen which load applied, mm^2

Figure 3.17: Specimen's dimension is being measured

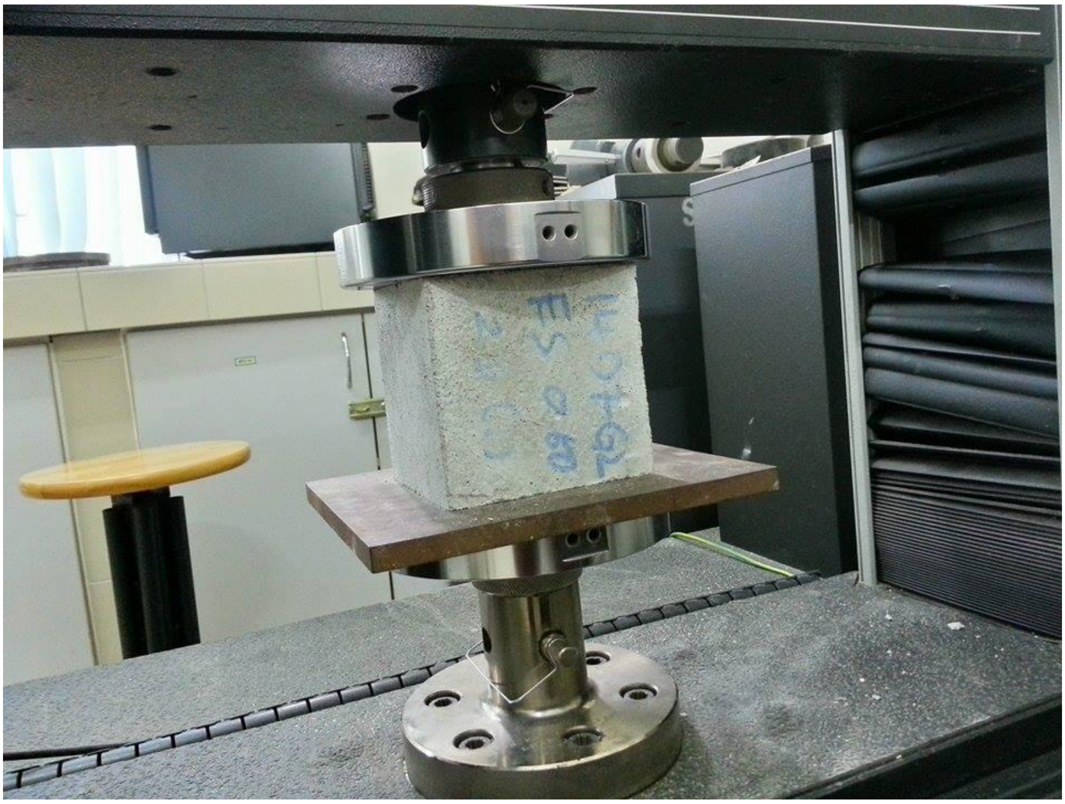

Figure 3.18: Compressive Strength Test Set-up

3.8.2 Splitting Tensile Strength Test (ASTM C496, 2004)

Theoretically, the splitting tensile strength is tends to be lower than compressive strength; it is about 10 % of compressive strength. In this study, the splitting tensile strength test was carried out in accordance with ASTM C496 (2004). An axial load with constant loading rate of 1.2 mm/min was applied on the cylindrical specimen with diameter of 100 mm and height of 200 mm until failure occurred on the testing specimen. As similar to compressive strength test, INSTON 5582 Testing Machine was used for the splitting tensile strength test. The splitting tensile strength test for LFCs were done in triplicate, but only the average values were reported in this study.

The cylindrical specimens were oven-dried for 24 hours before the splitting tensile strength test was carried out. The dimension of cylindrical specimen was measured using digital vernier caliper before the testing. Followed by that, it was placed in a steel mould and a thin plywood bearing strip was placed at the bottom and top of the cylindrical specimen. The plywood bearing strip was used for the cylindrical specimen to distribute the load evenly along the length of cylinder, as shown in Figure 3.19. Then, the cylindrical specimen was loaded with the specified rate of loading until the test specimen fails, as shown in Figure 3.20. The maximum load sustained by the cylindrical specimen was recorded and used for calculation of splitting tensile strength. Splitting tensile strength of cylindrical specimen is calculated using Equation 3.2.

$$T = \frac{2P}{\pi l d} \tag{3.2}$$

where

T = splitting tensile strength, MPa

P = maximum load sustained by specimen, N

l = length of specimen, mm

d = diameter of specimen, mm

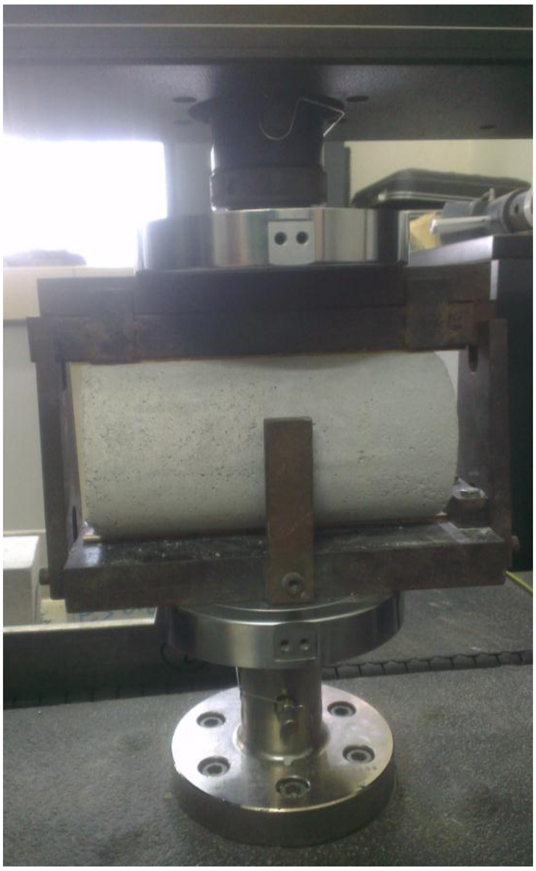

Figure 3.19: Splitting Tensile Strength Test Set-up

Figure 3.20: Failure mode of cylindrical specimen after tested its splitting tensile strength

3.8.3 Flexural Strength Test (ASTM C293, 2002)

For this experimental study, the flexural strength test or modulus of rupture was conducted in accordance with ASTM C293 (2002). Centre-point loading with constant loading rate of 0.1 mm/min was applied to prismatic specimen with dimension of 25 mm x 25 mm x 250 mm until failure occurred. The test was carried out using INSTON 5582 Testing Machine. The flexural strength test for LFCs were done in triplicate, but only the average values were reported in this study.

The prismatic specimens were oven-dried for 24 hours before the respective testing was conducted. Before testing, the dimension of prismatic specimen was measured using digital vernier caliper. An additional step was carried out for prismatic specimen. The centre point and an offset of 10 mm from both sides of the prism were marked to ease the placement of prims on the supporting blocks, as shown in Figure 3.21. Proper handling need to be taken since the prismatic specimen was small and brittle. Then, the prismatic specimen was loaded with the specified rate of loading until the test specimen fail. The maximum load sustained by the prismatic specimen was recorded and used for calculation of flexural strength. The flexural strength of prismatic specimen is calculated using Equation 3.3.

$$R = \frac{3PL}{2bd^2} \tag{3.3}$$

where

R = flexural strength, MPa

P = maximum load sustained by specimen, N

L = length of specimen, mm

b = average width of specimen, mm

d = average depth of specimen, mm

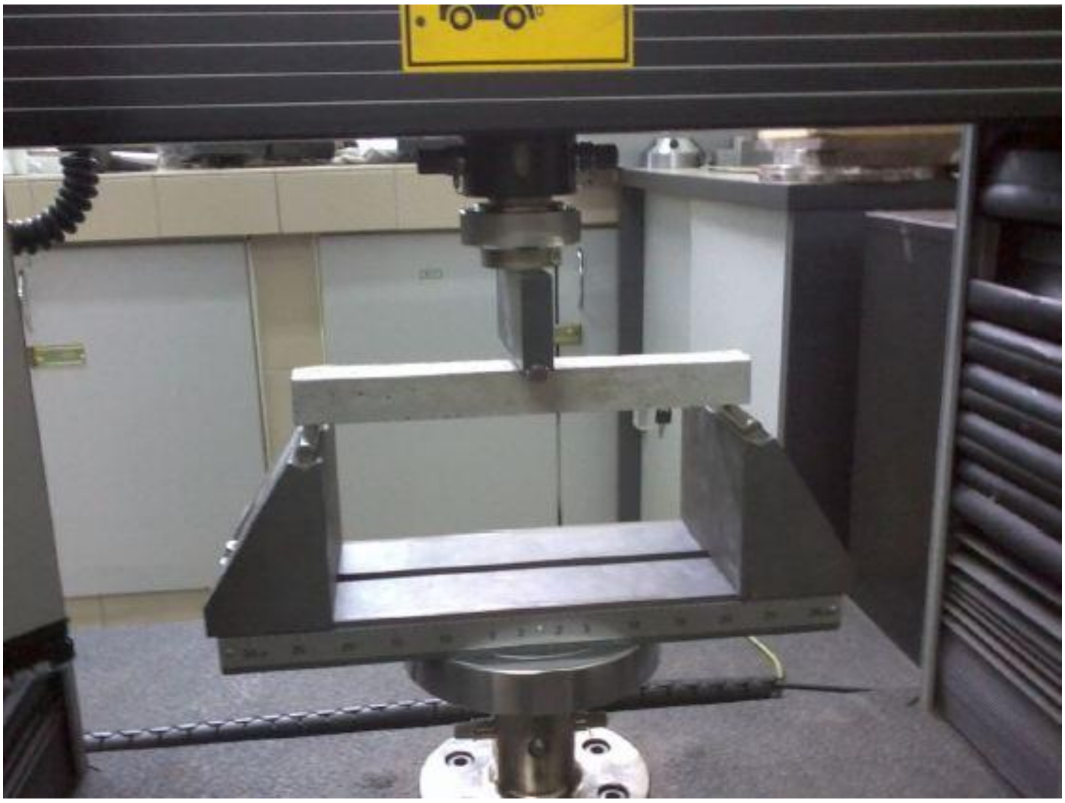

Figure 3.21: Flexural Strength Test Set-up

3.8.4 Poisson's Ratio Test (ASTM C469, 2002)

Poisson's ratio test was carried out according to ASTM C469 (2002). As similar to splitting tensile strength test, cylindrical specimen with diameter of 100 mm and height of 200 mm was used for the Poisson's ratio test. In this study, it was applied under a constant loading rate of 0.02 mm/s until the cylindrical specimen failed. INSTON 5582 Testing Machine was used to carry out the Poisson's ratio test. The Poisson's ratio test for LFCs were done in triplicate, but only the average values were reported in this study.

The cylindrical specimens were oven-dried for 24 hours before the Poisson's ratio test was carried out. The dimension of cylindrical specimen was measured using a digital vernier caliper as well as the centroid of cylinder at the side was marked. The testing surface of cylindrical specimen was flattened to ensure the load was distributed equally on the cylinder. For INSTON 5582 Testing Machine, it can only generate longitudinal strain on the cylindrical specimen. The lateral strain results were obtained through the Data Logger that connected with two LVDTs. The positions of two LVDTs that connected to Data Logger were adjusted and pointed to the centroid of the cylindrical specimen, as shown in Figure 3.22. Then, the cylindrical specimen was loaded under the specified rate of loading until failure was identified. The failure mode of cylindrical specimen after the Poisson's ratio test is shown in Figure 3.23. The lateral strains for every 0.5 MPa which shown on the Data Logger were obtained and recorded. The Poisson's ratio can be calculated using Equation 3.4.

$$\mu = \frac{\varepsilon_{t2} - \varepsilon_{t1}}{\varepsilon_2 - 0.000050} \tag{3.4}$$

where

μ = Poisson's ratio

ε_{t2} = transverse strain at mid-height of the specimen produced by stress corresponding to 40 % of ultimate load

ε_{t1} = transverse strain at mid-height of the specimen produced by stress corresponding to a longitudinal strain of 50 millionths

ε_2 = longitudinal strain produced by stress corresponding to 40 % of ultimate load

Figure 3.22: Poisson's Ratio Test Set-up

Figure 3.23: Failure mode of cylindrical specimens after the Poisson's ratio test

The static modulus of elasticity, E can be calculated by using the results obtained from Poisson's ratio test. Equation 3.5 is the formula of the modulus of elasticity, E.

$$E = \frac{S_2 - S_1}{\varepsilon_2 - 0.000050} \tag{3.5}$$

where

E = chord modulus of elasticity, MPa

S_2 = stress corresponding to 40 % of ultimate load

S_1 = stress corresponding to a longitudinal strain, ε_1, of 50 millionths, MPa

ε_2 = longitudinal strain produced by stress S_2

3.8.5 Compressive Toughness

In this study, compressive toughness was determined based on the stress-strain diagrams of Poisson's ratio. It refers to the areas under the vertical deformation of stress-strain diagrams. To determine the compressive toughness of the LFCs, integration method was adopted, as shown in Equation 3.6.

$$\mu_t = \int_0^{\varepsilon_f} \sigma \, d\varepsilon \tag{3.6}$$

where

μ_t = compressive toughness, J/m^3

ε = strain, 10^{-6} mm/mm

ε_f = strain upon failure, 10^{-6} mm/mm

σ = maximum compressive strength, MPa

3.9 Consistency and Stability

The consistency and stability of concrete mix were checked using the fresh density and hardened density of concrete specimen which recorded earlier. Theoretically, for both consistency and stability, the favourable ratio is nearly to unity. The consistency and stability of concrete mix are determined by using Equation 3.7 (Ramamurthy et al., 2009) and Equation 3.8 (Lim et al., 2013), respectively.

$$\text{Consistency} = \frac{\text{Fresh Density}}{\text{Designated Density}} \tag{3.7}$$

$$\text{Stability} = \frac{\text{Fresh Density}}{\text{Hardened Density}} \tag{3.8}$$

3.10 Performance Index

The objective of this experimental study is to obtain 1300 kg/m^3 of lightweight foamed concrete's density with tolerance ± 50 kg/m^3. However, the density for each concrete specimen was varying and it is not possible to obtain the same density for every concrete specimens. Therefore, in this study, performance indexes of the LFCs were calculated to obtain more accurate results. Performance index of concrete specimen is calculated using Equation 3.9.

$$\text{PI} = \frac{\text{f}}{\text{hardened density}/1000} \tag{3.9}$$

where

PI = performance index, MPa per 1000 kg/m^3

f = compressive strength, MPa

3.11 Microstructural Image Analysis (ASTM C1723, 2010)

The microstructural image analysis was conducted as complied with ASTM C1723 (2010) and by the mean of Scanning Electron Microscope (SEM). This microstructural study which performed in high vacuum with the application of a conductive coating was carried out under Hitachi VP-SEM S-3400N. The SEM imaging was conducted on 90-day curing period of lightweight foamed concrete for this experimental study. Before conducting the microstructural image analysis, a small piece of crushed concrete specimen was prepared and coated with a gold layer. The accelerating voltage of SEM was set to 15 kV and image with 500x, 1000x and 2000x of enlargements were selected for the microstructural analysis. Figure 3.24 shows the coating of specimen before SEM analysis was carried out while Figure 3.25 shows the Hitachi VP-SEM S-3400N which used for SEM.

Figure 3.24: Coating of specimen before SEM analysis

Figure 3.25: Hitachi VP-SEM S-3700N

Besides that, Energy-dispersive X-Ray spectroscopy (EDS) is microstructural image analysis equipment which used for the elemental composition analysis of chemical characterization of concrete sample. It relies on the interaction between X-ray excitation and the concrete sample to determine elemental composition of concrete sample. It is attached together with Hitachi VP-SEM S-3400N. Both of the microstructural image analysis for concrete specimen, namely SEM and EDS are carried out at the same time. Figure 3.26 shows the close shot of EDS which attached together with Hitachi VP-SEM S-3400N.

Figure 3.26: Energy-Dispersive X-Ray Spectroscopy (EDS)

3.12 Summary

Raw materials of concrete mix were prepared accordingly. Lightweight foamed concrete for control mix and those with 7.5 % of eggshell as partial cement replacement material were casted using pre-foaming method, where stable and dry foam was added into the fresh lightweight foamed concrete until the designated density was achieved. The density of foam was 45 kg/m^3 and it was produced by mixing water and liquid synthetic foaming agent with ratio of 1:30 in a foam generator. The density was controlled at density of 1300 kg/m^3 with tolerance $\pm$ 50 kg/m^3. Two types of mix proportion were prepared in this experimental study to determine the optimal water to cement ratio, which are lightweight foamed concrete with 100 % pure cement as control mix (LFC-CTR) and 7.5 % of eggshell as partial cement replacement material (LFC-ES7.5). Sufficient amount of specimens in cube, cylinder and prism were prepared to obtain the average value of results. At least 3 sets of results were needed from each batch of concrete mixing. All the concrete specimens were cured in water tank for 7, 28, 56, 90 and 180 days of ages. The destructive tests namely compressive strength test, splitting tensile strength test, flexural strength test and Poisson's ratio test were conducted. Small piece of crushed

90-day and 180-day LFC specimens for each mix proportion were prepared for microstructural analysis. The accelerating voltage of SEM was set to 15 kV and image with 500x, 1000x and 2000x of magnifications were selected for the microstructural analysis.

CHAPTER 4

SCREENING OF TRIAL MIXES RESULTS

4.1 Introduction

This chapter mainly focuses on the mix proportion, fresh properties and compressive strength of lightweight foamed concrete with 7.5 % of eggshell as partial cement replacement material, LFC-ES7.5 and lightweight foamed concrete with 100 % pure cement, LFC-CTR as comparison purpose. All of the concrete specimens were cured in water for 7 days and 28 days of ages before compressive strength testing.

4.2 Control Mix

The control mix of pure lightweight foamed concrete, LFC-CTR (contained only ordinary Portland cement, fine aggregates and water) set a base line reference and standard guideline for further study as compared with LFC-ES7.5 (7.5 % of eggshell powder as part of cement replacement). Consistency, stability, compressive strength and performance index of the concrete specimen were studied. Table 4.1 shows the mix proportion of the control mixes, LFC-CTR with water to cement ratios ranging from 0.52 to 0.60, with interval of 0.04.

Table 4.1: Mix Proportion of Control Mixes, LFC-CTR

Specimen	[2]w/c	Material (kg/m^3)				
		Cement	Eggshell	Sand	Water	Foam
LFC-CTR[1]-0.52	0.52	500	0	500	260	18.9
LFC-CTR-0.56	0.56	500	0	500	280	17.9
LFC-CTR-0.60	0.60	500	0	500	300	16.6

Note:

[1]LFC-CTR = lightweight foamed concrete with 100 % pure cement

[2]w/c = water to cement ratio

Table 4.1 shows that the amount of foam used for LFC-CTR is in decreasing trend corresponding to the increasing in water to cement ratio. Increase in water to cement ratio helps to increase the inter-particle lubrication and decrease the bulk density of the LFCs.

4.2.1 Fresh Properties of Control Mix

Several tests were carried out to determine the fresh properties of LFC-CTR such as fresh density test, flow table spread test and inverted slump test. The desired density for casting of the LFCs is fixed at 1300 kg/m^3. Table 4.2 shows the fresh properties for LFC-CTR with different water to cement ratios.

Table 4.2: Fresh Properties of LFC-CTR at Three Different W/C Ratios

Specimen	Fresh density (kg/m^3)	Flow Table Spread, number of drop	Average Inverted Slump Diameter (mm)	Stability	Consistency
LFC-CTR-0.52	1319	>250 (21 drops)	541.25	0.938	1.015
LFC-CTR-0.56	1340	>250 (16 drops)	677.50	0.915	1.031
LFC-CTR-0.60	1255	>250 (4 drops)	776.25	0.973	0.965

The fresh densities of various LFC-CTR mixes were controlled in the range of 1300 kg/m^3 ± 50 kg/m^3. Table 4.2 shows that when the water to cement ratio increases, the number of drop of flow table test decreases due to increasing of the workability. Increase in water to cement ratio causes the free water content in the concrete increased. Free water content made the fresh concrete to be more workable and flowable. Besides that, the average inverted slump diameter increases as well as the water to cement ratio increases due to the similar factor.

The density of concrete mixing also tends to be quite consistent and stable. The stability of LFC specimens for all three water to cement ratios are nearly to unity. The foams in the LFCs maintained its stability and firmness well.

4.2.2 Compressive Strength of Control Mix

7 and 28 days compressive strength of LFC-CTR were studied in order to determine its optimal water to cement ratio. Various types of densities of LFC-CTR were listed in Table 4.3. Figure 4.1 shows the compressive strength of LFC-CTR at 7 and 28 days of ages.

Table 4.3: Various Types of Densities of LFC-CTR

Specimen	Fresh density of mortar (kg/m³)	Fresh density for foamed concrete (kg/m³)	Hardened density (kg/m³)	Density after 24 hours- oven dry (kg/m³)		Percentage error (%)	
				7 Days	28 Days	7 Days	28 Days
LFC-CTR-0.52	1954	1319	1406.4	1317.5	1362.0	6.32	3.16
LFC-CTR-0.56	2014	1340	1465.1	1265.4	1204.5	13.63	17.79
LFC-CTR-0.60	2076	1255	1290.3	1240.0	1250.0	3.90	3.12

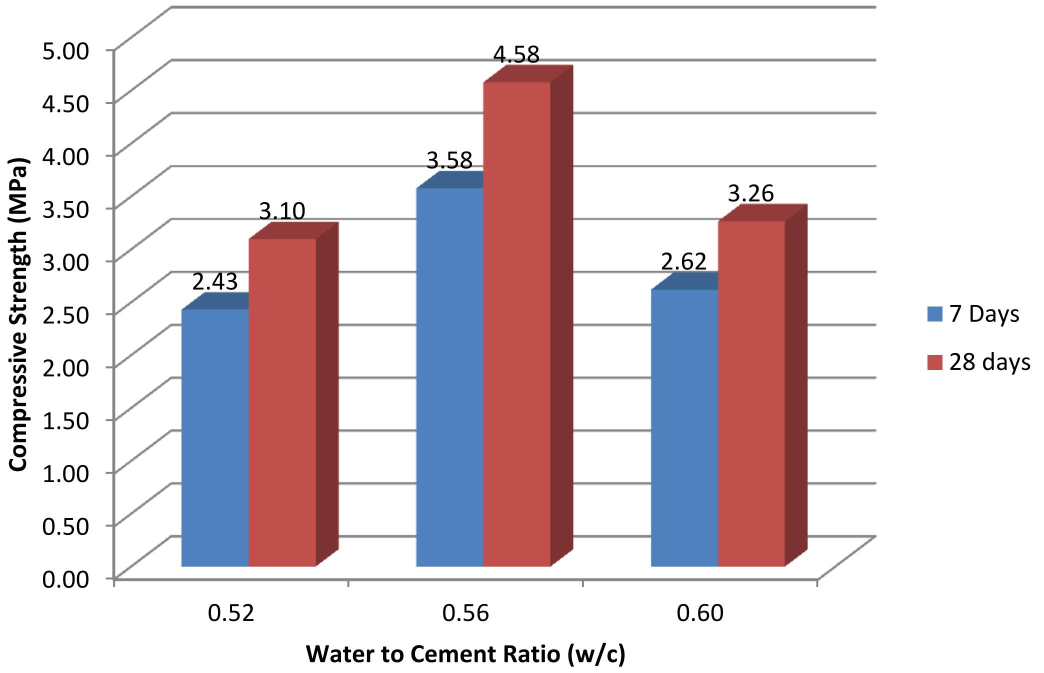

Figure 4.1: 7 and 28 Days Compressive Strength of LFC-CTR at Three Different W/C Ratios

Based on Figure 4.1, LFC-CTR-0.56 achieved the highest compressive strength as compared with others for both 7 days and 28 days curing periods. Based on the results, 0.56 was determined as the optimal water to cement ratio for LFC-CTR.

4.2.3 Performance Index of Control Mix

Performance index is a method used to determine the concrete's strength performance based on the density of the concrete cube. In this study, a desired density of 1300 kg/m^3 had to be maintained. However, it is very difficult to maintain the desired density for each of the samples. Therefore, performance index is needed for comparison purpose. The performance index can be calculated by dividing the compressive strength with respective density. In this case, a high value of performance index is preferable. Figure 4.2 shows the relationship among 7 and 28 days performance index and average inverted slump diameter with water to cement ratio for LFC-CTR.

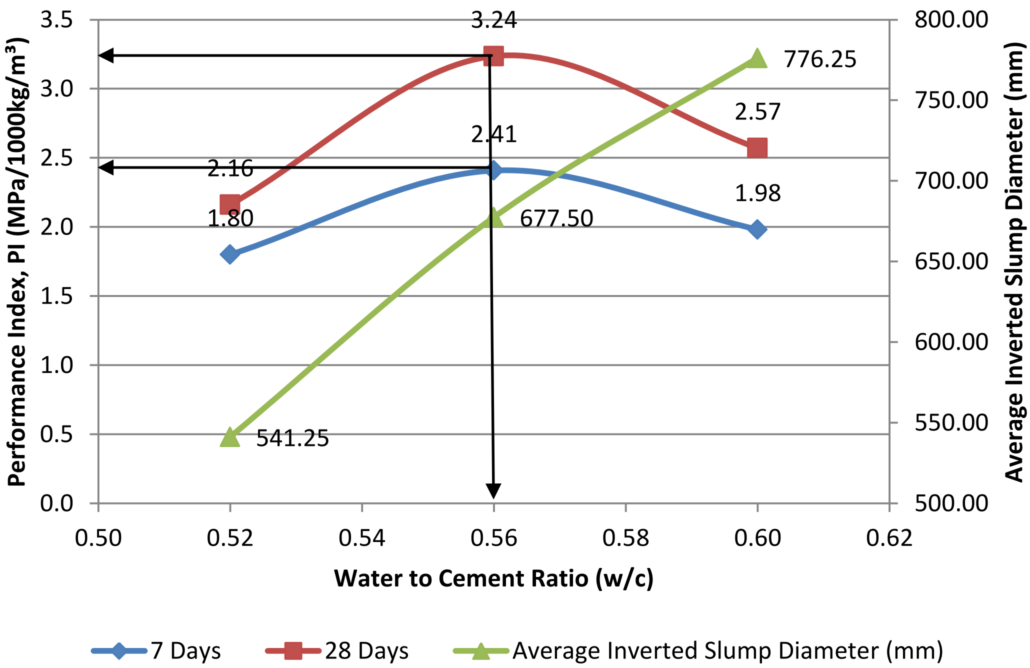

Figure 4.2: Relationship among 7 and 28 Days Performance Index, Average Inverted Slump Diameter and Water to Cement Ratio for LFC-CTR

Optimal water to cement ratio is chosen based on the highest performance index. The bell curves of performance index values for both 7 days and 28 days of ages show that the optimal water to cement ratio for LFC-CTR is 0.56 as indicated.

4.3 Trial Mix

Table 4.4 shows the mix proportion of LFC-ES7.5 with water to cement ratios ranging from 0.52 to 0.60, at an interval of 0.04.

Table 4.4: Mix Proportion of LFC-ES7.5

Specimen	[2]w/c	Material (kg/m^3)				
		Cement	Eggshell	Sand	Water	Foam
LFC-ES7.5[1]-0.52	0.52	462.5	37.5	500	260	19.9
LFC-ES7.5-0.56	0.56	462.5	37.5	500	280	18.7
LFC-ES7.5-0.60	0.60	462.5	37.5	500	300	18.1

Note:

[1]LFC-ES7.5 = lightweight foamed concrete with 7.5% of eggshell powder as partial cement replacement material

[2]w/c = water to cement ratio

Table 4.4 shows that the amount of foam is decreasing corresponding to the increasing of the water to cement ratio. The reason is similar with that of LFC-CTR. However, amount of foam used for LFC-ES7.5 is relatively higher than that of LFC-CTR for the equivalent water to cement ratio. This may due to the porous structure of eggshell which enhances the water absorption.

4.3.1 Fresh Properties of Trial Mix

The results of fresh properties for LFC-ES7.5 with different water to cement ratios were obtained and tabulated in Table 4.5.

Table 4.5: Fresh Properties of LFC-ES7.5 at Three Different W/C Ratios

Specimen	Fresh Density (kg/m^3)	Flow Table Spread, number of drop	Average Inverted Slump Diameter (mm)	Stability	Consistency
LFC-ES7.5-0.52	1330	>250 (24 drops)	498.75	0.960	1.023
LFC-ES7.5-0.56	1349	>250 (21 drops)	602.50	0.982	1.038
LFC-ES7.5-0.60	1321	>250 (9 drops)	665.00	0.973	1.016

The average inverted slump value is increasing corresponding to the increase of water to cement ratio, which is similar with that of LFC-CTR. However, LFC-ES7.5 develops an overall lower slump value than LFC-CTR. The reason is due to the porous structure of eggshell which enhances the water absorption. Furthermore, finer particle size of eggshell powder is one of the reasons that cause the LFC-ES7.5 to develop a lower slump value as compared to that of LFC-CTR. Finer size of particle which has larger total surface area need more water to perform the same workability.

For the consistency and stability of LFC-ES7.5 for all three water to cement ratios, the values are nearly to unity, as similar to LFC-CTR. This means that the foams in LFC-ES7.5 maintained its stability and firmness well.

4.3.2 Compressive Strength of Trial Mix

Compressive strength of concrete always the most essential part that needs to be discussed for any study and investigation related to concrete. Therefore, the effect of 7.5 % eggshell of total cement weight for cement replacement to the compressive strength of concrete is discussed in this section. Table 4.6 shows the various types of density at 7 and 28 days of curing periods for LFC-ES7.5. Figure 4.3 shows the compressive strength of LFC-ES7.5 at 7 and 28 days of ages.

Table 4.6: Various Types of Densities of LFC-ES7.5

Specimen	Fresh density of mortar (kg/m³)	Fresh density for foamed concrete (kg/m³)	Hardened density (kg/m³)	Density after 24 hours- oven dry (kg/m³)		Percentage error (%)	
				7 Days	28 Days	7 Days	28 Days
LFC-ES7.5-0.52	1954	1330	1385.1	1301.0	1330.3	6.07	3.96
LFC-ES7.5-0.56	1887	1349	1373.2	1302.0	1322.0	5.18	3.73
LFC-ES7.5-0.60	1955	1321	1358.3	1288.0	1320.0	5.15	2.82

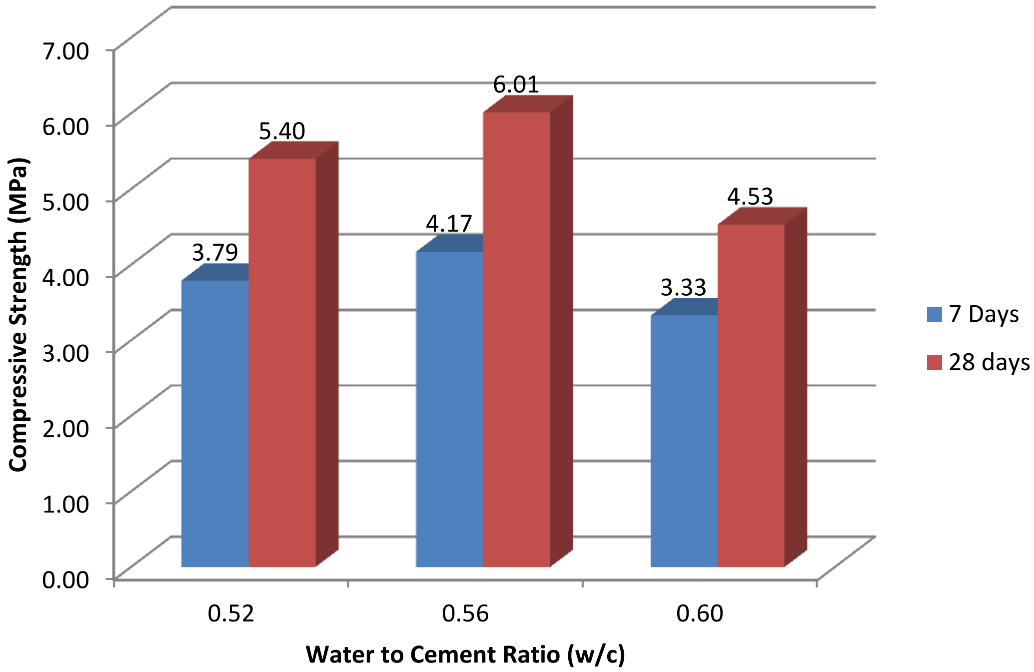

Figure 4.3: 7 and 28 Days Compressive Strength of LFC-ES7.5 at Three Different Water to Cement Ratios

Figure 4.3 shows that the highest strength is achieved by concrete with water to cement ratio of 0.56, which is 4.17 MPa and 6.01 MPa at 7 days and 28 days of ages respectively. As the water to cement ratio increase from 0.52 to 0.56, it shows an obvious trend with the increasing of compressive strength and a decreasing trend as the water to cement ratio increase from 0.56 to 0.60. Hence, the optimal water to cement ratio of LFC-ES7.5 is determined as 0.56 according to the results.

4.3.3 Performance Index of Trial Mix

Figure 4.4 shows the summary of performance index and average inverted slump diameter with different water to cement ratios for LFC-ES7.5.

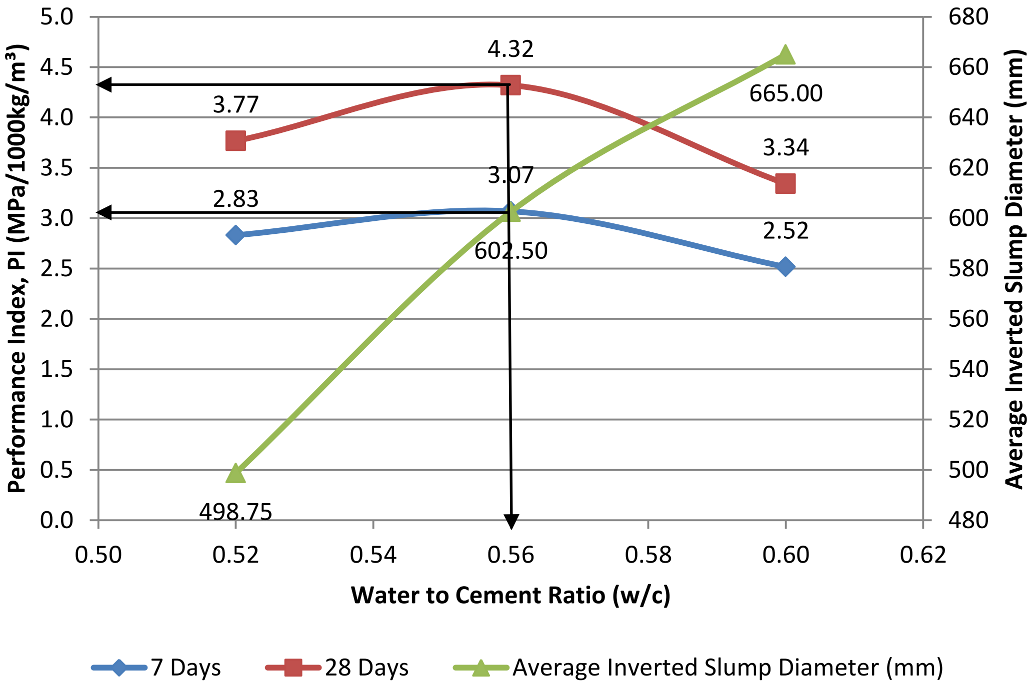

Figure 4.4: Relationship among 7 and 28 Days Performance Index, Average Inverted Slump Diameter and Water to Cement Ratio for LFC-ES7.5

Based on Figure 4.4, the bell curves of performance index values for both 7 days and 28 days of ages show that the optimal water to cement ratio for LFC-ES7.5 is 0.56 as indicated.

4.4 Summary

From the results obtained, the optimal water to cement ratio for both trial mixes of LFC-CTR and LFC-ES7.5 was determined as 0.56. Therefore, water to cement ratio of 0.56 was adopted for further study on the effect of the cement replacement with eggshell powder in the lightweight foamed concrete on its engineering properties in terms of compressive, splitting tensile and flexural strengths, Poisson's ratio as well as compressive toughness.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Introduction

This chapter discusses about the results of several tests carried out on lightweight foamed concrete with 100% pure cement, namely LFC-CTR and lightweight foamed concrete with 7.5 % of eggshell powder as partial cement replacement material, namely LFC-ES7.5 after obtained the optimal water to cement ratio. All the specimens were water cured for 7, 28, 56, 90 and 180 days of ages before testing. The effects of adding eggshell as cement replacement material on its engineering properties in terms of compressive, splitting tensile and flexural strengths, Poisson's ratio as well as compressive toughness are discussed in this chapter.

5.2 Mix Proportions

Table 5.1 presents the mix proportions used in this study for both LFC-CTR and LFC-ES7.5.

Table 5.1: Mix Proportions

Specimen	w/c[4]	Material (kg/m³)					Average Inverted Slump Diameter (mm)	Consistency	Stability
		Cement	Eggshell	Sand	Water	Foam			
LFC-CTR[1]-0.56[3]	0.56	500	0	500	280	17.9	677.50	0.915	1.031
LFC-ES7.5[2]-0.56	0.56	462.5	37.5	500	280	18.7	602.50	0.982	1.038

Note:

[1]LFC-CTR = lightweight foamed concrete with 100 % pure cement

[2]LFC-ES7.5 = lightweight foamed concrete with 7.5% of eggshell powder as partial cement replacement material

[3]0.56 is the optimal water to cement ratio

[4]w/c = water to cement ratio

5.3 Compressive Strength

The compressive strengths for both LFC-CTR and LFC-ES7.5 are illustrated in Figure 5.1.

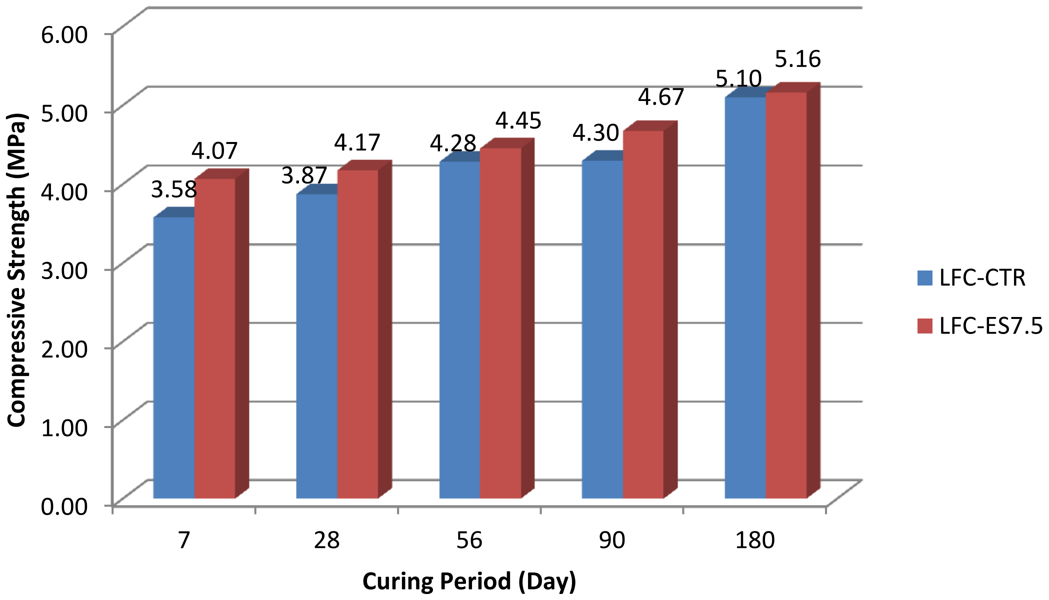

Figure 5.1: Compressive Strength Development from 7 to 180 Days of Curing Periods for LFC-CTR and LFC-ES7.5

Figure 5.1 shows that the compressive strength development trend is increasing from 7 days to 180 days of curing period for both LFC-CTR and LFC-ES7.5. This is due to the hydration process that promoting the continuing formation of C-S-H gel by reaction of cement and water under water curing condition. By comparing the results of LFC-CTR and LFC-ES7.5 which shown in Figure 5.1, the compressive strength achieved by LFC-ES7.5 is higher than that of LFC-CTR at every ages. As the curing period increases, the compressive strength of both LFC-CTR and LFC-ES7.5 increase but incremental of compressive strength for LFC-CTR is higher than that of LFC-ES7.5. The incremental of compressive strength from 7 days to 180 days of ages for LFC-CTR and LFC-ES7.5 are 1.52 MPa and 1.09 MPa respectively. However, LFC-ES7.5 still possesses the highest compressive strength at 180-day of curing age which is 5.16 MPa.

According to Tsai *et al.*'s study (as cited in Stadelman, 2000), 94% of eggshell powder is made of calcium carbonate. There are another researchers stated that the purpose of calcium carbonate is to accelerate the hydration of tri-calcium silicate which responsible for the early strength of concrete (Matschei *et al.*, 2006).

Besides that, addition of calcium carbonate can act as inert filler within concrete specimen as well (Matschei *et al*., 2006). Inert filler will help in filling up the pores within concrete which in turns results in a less porous microstructure, thus increasing the compressive strength of concrete. Table 5.2 shows the compressive strength of LFC-ES7.5 at 180 days of curing period is 1 % higher than that of LFC-CTR.

Table 5.2: Effect of Incorporation of Eggshell in LFC on its Compressive Strength at 180 Days of Curing Period

Age	Mix	Percentage of strength of LFC-ES7.5 corresponded to that of control mix at 180 days of curing period
180 days	LFC-CTR	100
	LFC-ES7.5	101

Besides that, it was found that the microstructure of LFC was denser compared with that of LFC-CTR which further justify that incorporation of eggshell in the LFC helped in increasing its compressive strength. Figures 5.2 and 5.3 present the microstructural images with 500x, 1000x and 2000x of magnifications for both LFC-CTR and LFC-ES7.5 respectively at 90 days of curing period.

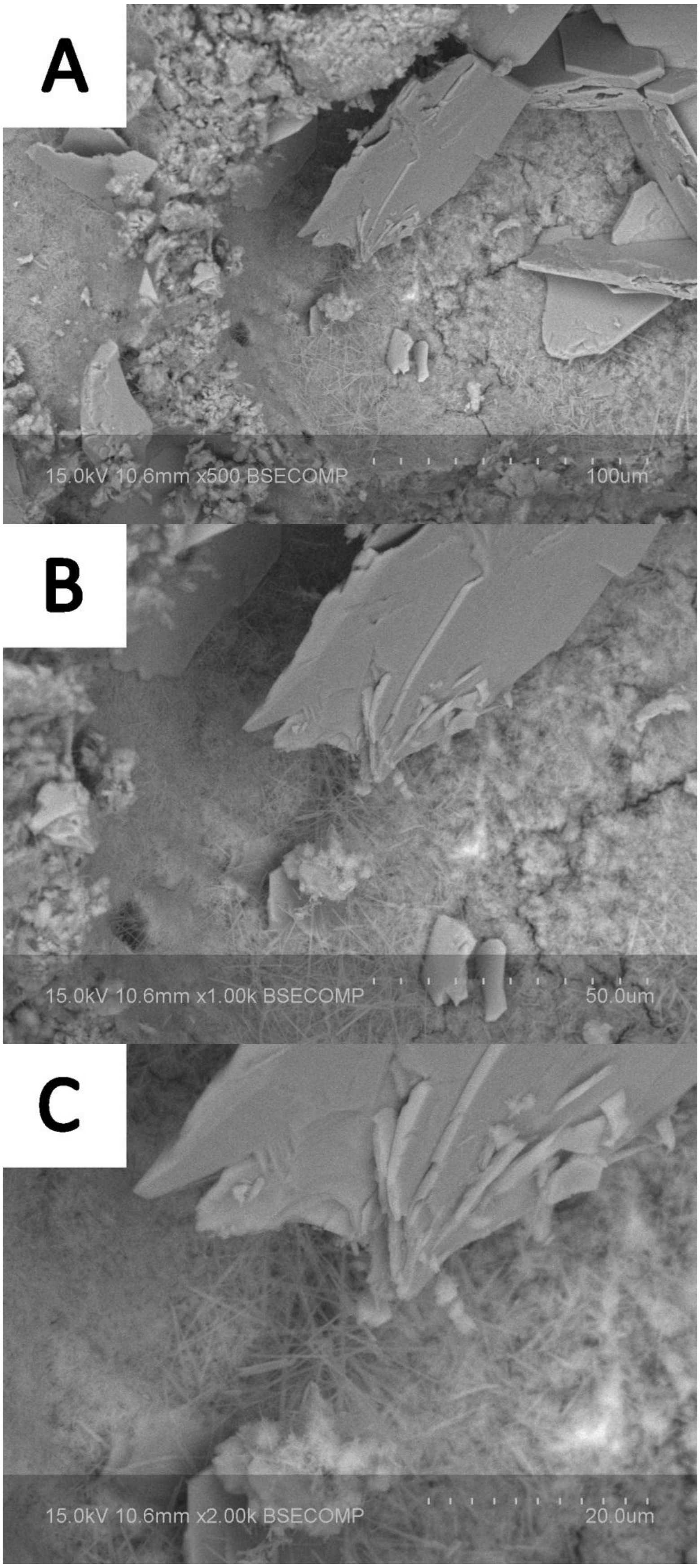

Figure 5.2: Microstructural Images of LFC-CTR at 90 Days of Curing Period: (A) 500x, (B) 1000x, (C) 2000x of magnification

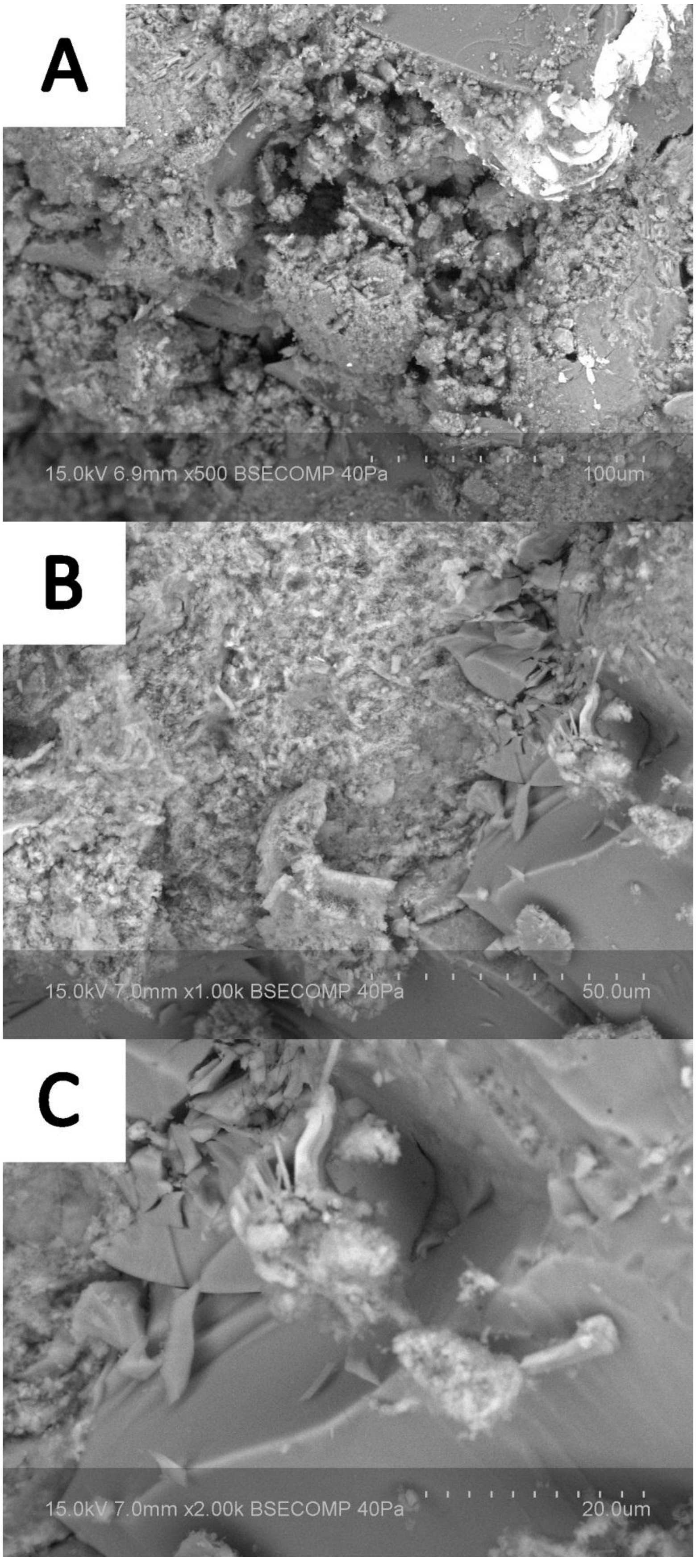

Figure 5.3: Microstructural Images of LFC-ES7.5 at 90 Days of Curing Period: (A) 500x, (B) 1000x, (C) 2000x of magnification

5.4 Splitting Tensile Strength

The splitting tensile strengths for both LFC-CTR and LFC-ES7.5 are illustrated in Figure 5.4.

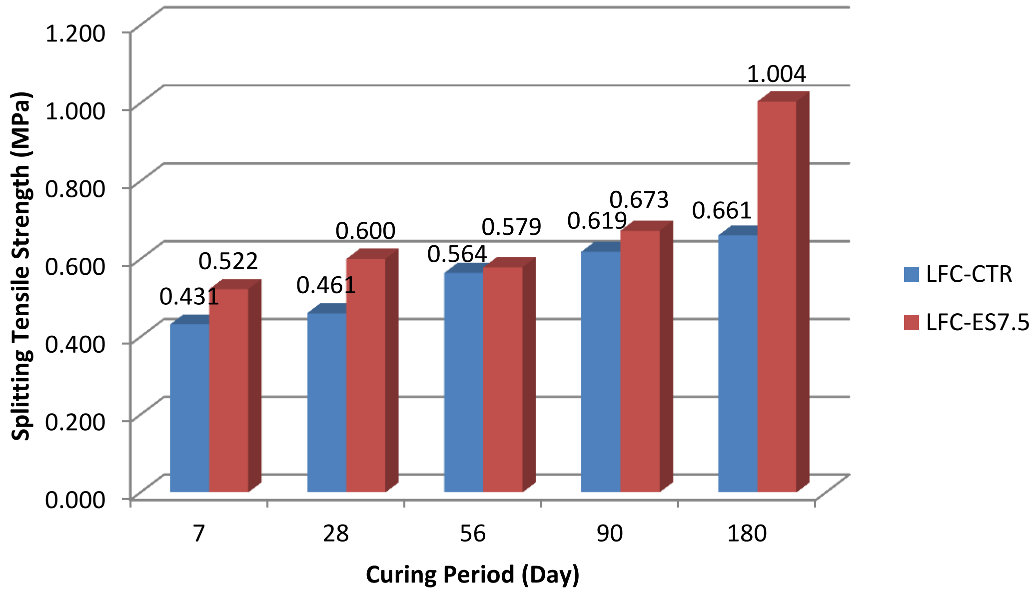

Figure 5.4: Splitting Tensile Strength Development from 7 to 180 Days of Curing Periods for LFC-CTR and LFC-ES7.5

Figure 5.4 shows the splitting tensile strength for both mix proportions increased along with the curing periods from 7 to 180 days. LFC-ES7.5 achieved the highest splitting tensile strength which is 1.004 MPa at 180 days of curing period. The strength gaps between LFC-CTR and LFC-ES7.5 at 7 days and 180 days of curing periods are 0.091 MPa and 0.343 MPa respectively. Apparently, this shows that LFC-ES7.5 has a better later strength performance. This may due to the replacement of eggshell powder slightly reduce the content of tri-calcium silicate, C_3S that responsible for early strength of concrete. LFC-ES7.5 also serves a better performance in increasing the tensile strength of concrete at 180 days of curing period.

Figure 5.4 shows that splitting tensile strength of LFC-ES7.5 at 28 days of curing period is slightly higher than that of 56 days of age. The results are further studied by using performance index method which is an equivalent platform for comparison.

Generally, both compressive and splitting tensile strengths development sharing the same trend which the strengths gained increased throughout the curing periods. Based on Figure 5.4, LFC-ES7.5 achieved higher splitting tensile strength than that of LFC-CTR in overall. Theoretically, splitting tensile strength is related to compressive strength but this relationship also dependents on other factors such as aggregate type, particle size distribution, curing period of concrete, curing process and air content (Parra, 2011). Based on the relationship between splitting tensile strength and compressive strength as illustrated in Figure 5.5, the splitting tensile strength is directly proportional to compressive strength.

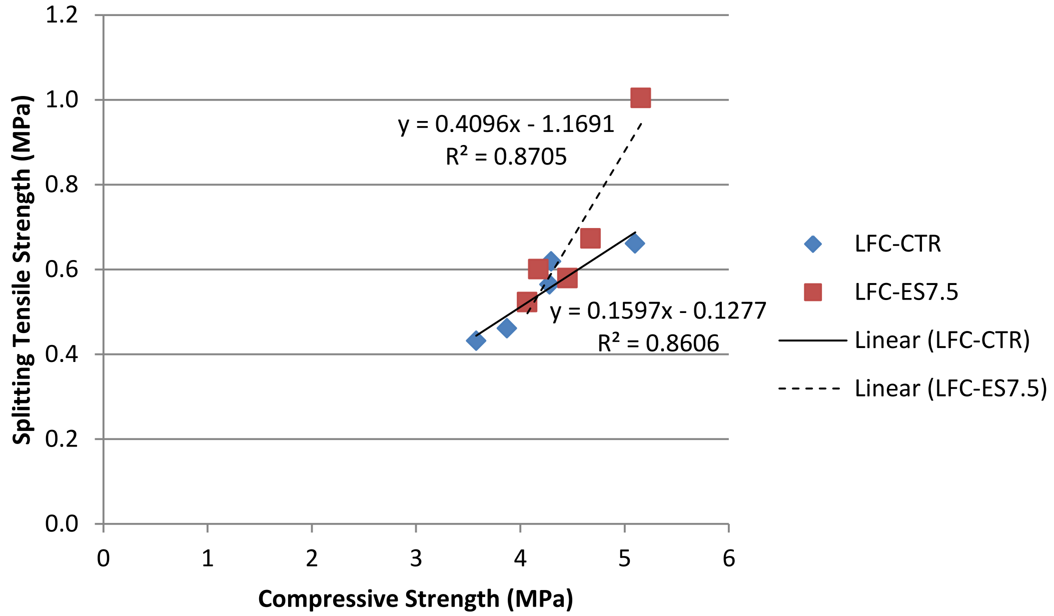

Figure 5.5: Relationship of Splitting Tensile Strength and Compressive Strength for LFC-CTR and LFC-ES7.5

Table 5.5 shows the splitting tensile strength of LFC-ES7.5 at 180 days of curing period is 52 % higher than that of LFC-CTR.

Table 5.3: Effect of Incorporation of Eggshell in LFC on its Splitting Tensile Strength at 180 Days of Curing Period

Age	Mix	Percentage of strength of LFC-ES7.5 corresponded to that of control mix at 180 days of curing period
180 days	LFC-CTR	100
	LFC-ES7.5	152

5.5 Flexural Strength

The flexural strengths for both LFC-CTR and LFC-ES7.5 are presented in Figure 5.6.

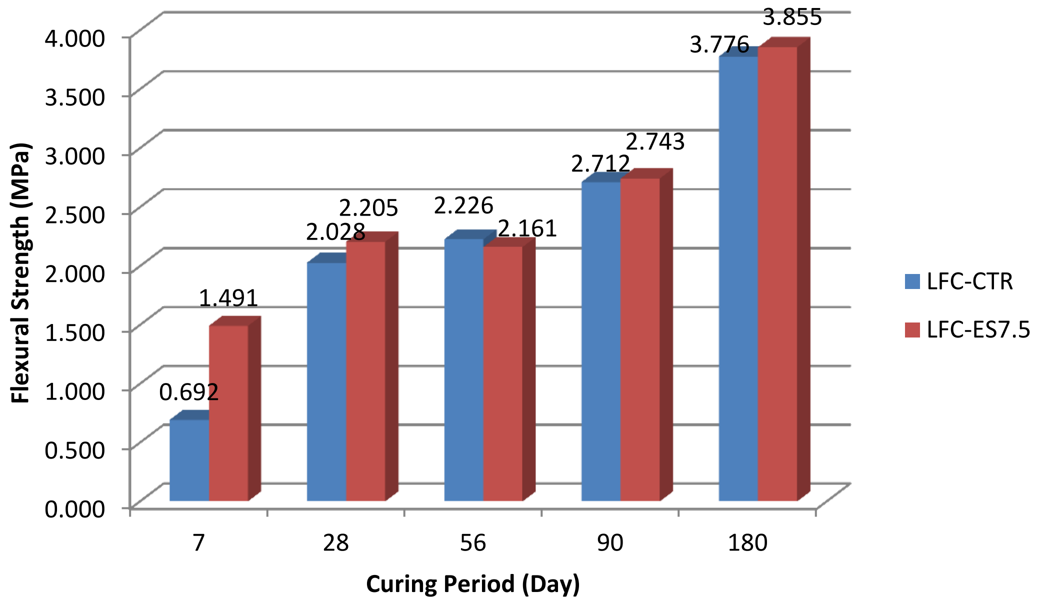

Figure 5.6: Flexural Strength Development from 7 to 180 Days of Curing Periods for LFC-CTR and LFC-ES7.5

Figure 5.6 shows the flexural strength for both mixes increased throughout the curing periods from 7 to 180 days of ages. Based on the trend of data, LFC-ES7.5 achieved the highest flexural strength at 180 days of curing period which is 3.855 MPa.

As similar to splitting tensile strength development trend, flexural strength of LFC-ES7.5 at 28 days of age is slightly higher than that at 56 days of age. Lower flexural strength at 56 days of curing period as compared to that of 28 days of curing period was due to the lower hardened density of concrete specimens at 56 days of curing period which in turns leading to a lower flexural strength. Performance index method was adopted to provide a similar platform for the strengths comparison.

Basically, the flexural strength development possesses same trend with both the compressive strength and splitting tensile strength development which shown in sections 5.3 and 5.4. Based on Figure 5.6, LFC-ES7.5 achieved higher flexural strength as compared to that of LFC-CTR in overall. Based on the relationship between flexural strength and compressive strength illustrated in Figure 5.7, the flexural strength is directly proportional to compressive strength.

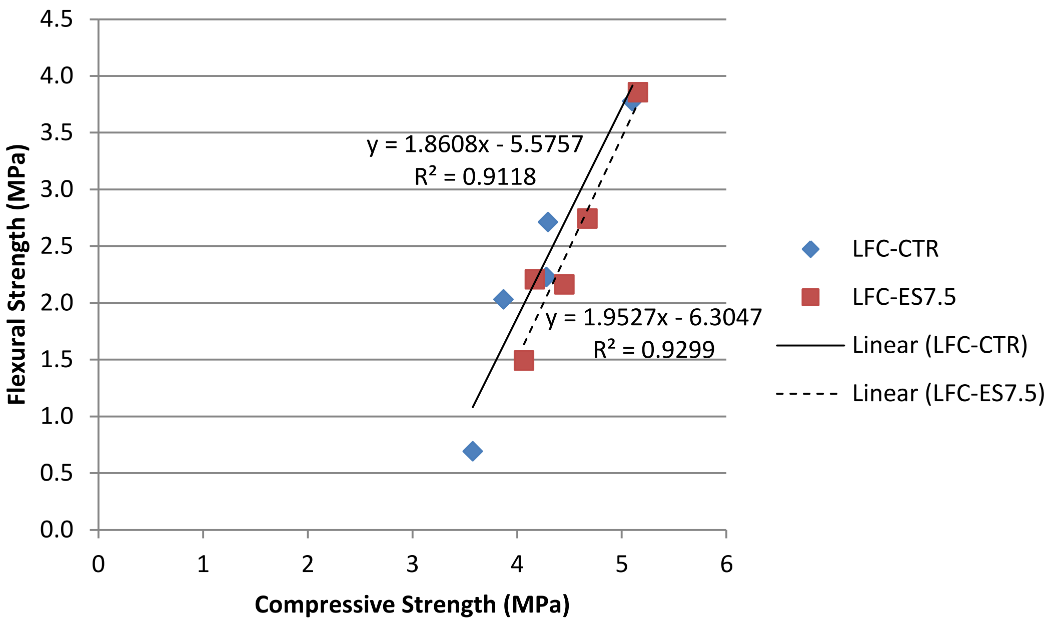

Figure 5.7: Relationship of Flexural Strength and Compressive Strength for LFC-CTR and LFC-ES7.5

Table 5.4 shows the flexural strength of LFC-ES7.5 at 180 days of curing period is 2 % higher than that of LFC-CTR.

Table 5.4: Effect of Incorporation of Eggshell in LFC on its Flexural Strength at 180 Days of Curing Period

Age	Mix	Percentage of strength of LFC-ES7.5 corresponded to that of control mix at 180 days of curing period
180 days	LFC-CTR	100%
	LFC-ES7.5	102%

5.6 Poisson's Ratio

The Poisson's ratios for 90 days of curing period of LFC-CTR and LFC-ES7.5 are illustrated in Table 5.5.

Table 5.5: Poisson's Ratio for LFC-CTR and LFC-ES7.5 at 90 Days of Curing Period

Curing Period	Specimens Series No.	40 % of Maximum Compressive Strength (MPa)	ε_{t2} [1]	ε_{t1} [2]	ε_{2} [3]	Poisson's ratio, μ [4]
90-Day	LFC-CTR-0.56	1.20	0.000268	0.0000071	0.00260	0.102
	LFC-ES7.5-0.56	1.88	0.000583	0.0000130	0.00271	0.214

Note:

[1] ε_{t2} = transverse strain at mid-height of the specimen produced by stress corresponding to 40 % of ultimate load

[2] ε_{t1} = transverse strain at mid-height of the specimen produced by stress corresponding to a longitudinal strain of 50 millionths

[3] ε_{2} = longitudinal strain produced by stress corresponding to 40 % of ultimate load

[4] $\mu = (\varepsilon_{t2} - \varepsilon_{t1})/(\varepsilon_{2} - 0.000050)$

As discussed in section 5.3, the compressive strength of LFC-ES7.5 was noticed to be higher than that of LFC-CTR. Table 5.5 shows that LFC-ES7.5 possesses higher Poisson's ratio than that of LFC-CTR at 90 days of age, which is 0.214. This shows that LFC-ES7.5 tends to possess higher deformation at horizontal axis as compared to that of LFC-CTR.

The static modulus of elasticity for 90 days of curing period of LFC-CTR and LFC-ES7.5 are illustrated in Table 5.6.

Table 5.6: Static Modulus of Elasticity for LFC-CTR and LFC-ES7.5 at 90 Days of Curing Period

Curing Period	Specimens Series No.	40 % of Maximum Compressive Strength, S_2[1] (MPa)	S_1[2] (MPa)	ε_2[3]	Static Modulus of Elasticity, E[4] (MPa)
90-Day	LFC-CTR-0.56	1.20	0.0146	0.00260	463
	LFC-ES7.5-0.56	1.88	0.0232	0.00271	698

Note:

[1] S_2 = stress corresponding to 40 % of ultimate load

[2] S_1 = stress corresponding to a longitudinal strain, ε_1, of 50 millionths, MPa

[3] ε_2 = longitudinal strain produced by stress S_2

[4] $E = (S_2 - S_1)/(\varepsilon_2 - 0.000050)$

According to Neville (2011b), the static modulus of elasticity of concrete was found not to be affected by curing. Hence, static modulus of elasticity will only be used to compare against LFC-CTR and LFC-ES7.5 for the same curing period. Generally, static modulus of elasticity increase corresponding to the increasing of compressive strength of concrete. Based on Table 5.6, LFC-ES7.5 possesses higher static modulus of elasticity than that of LFC-CTR at 90 days of curing period, which is 698 MPa. This means that LFC-ES7.5 tends to be more rigid and elastic as compared to that of LFC-CTR.

5.7 Compressive Toughness

The compressive toughness values of LFC-CTR and LFC-ES7.5 at 90 days of curing period are illustrated in Figures 5.8 and 5.9 respectively.

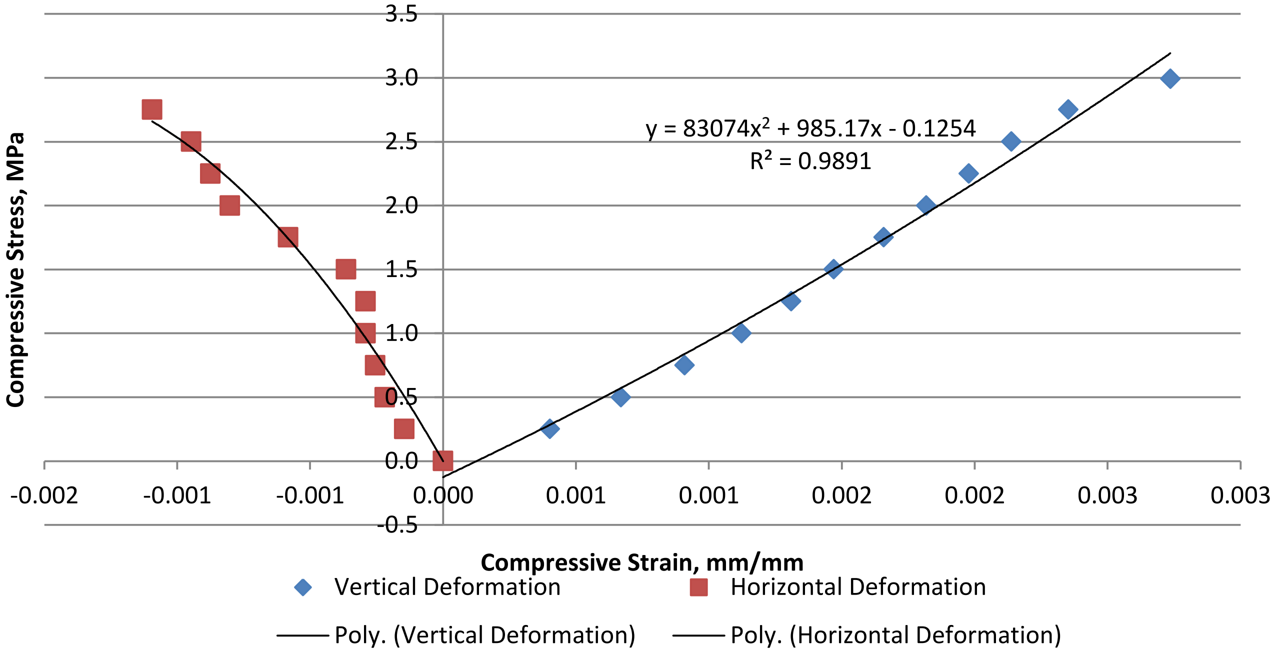

Figure 5.8: 90-Day Compressive Stress-Strain Relationship of LFC-CTR-0.56

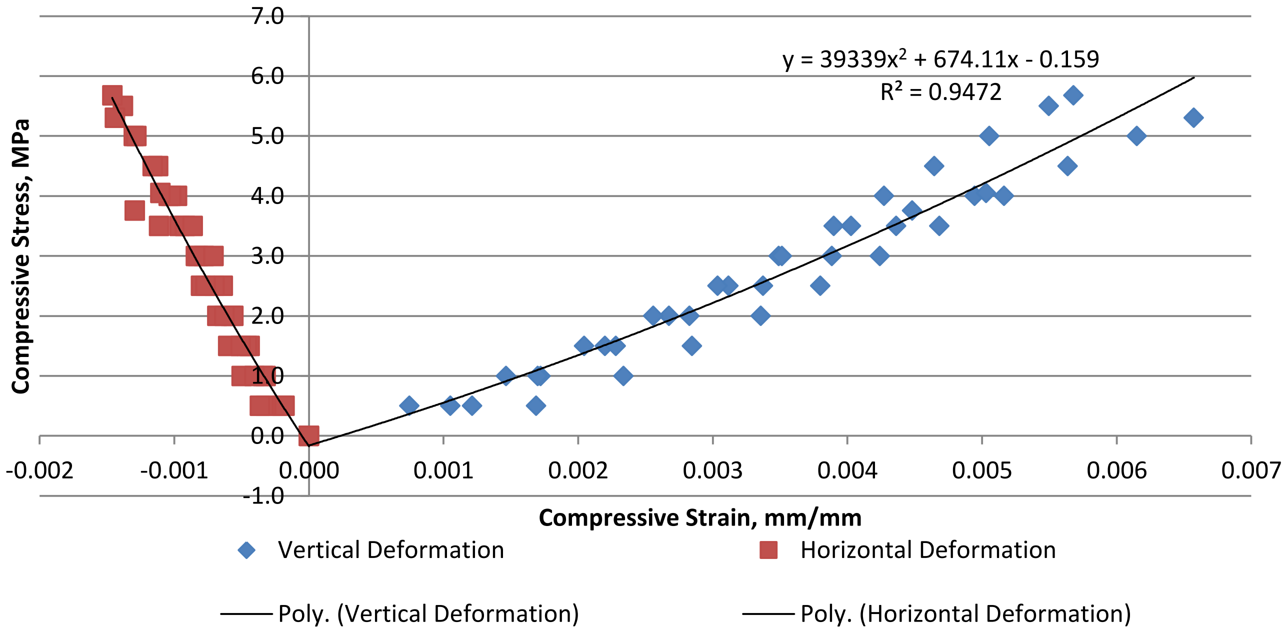

Figure 5.9: 90-Day Compressive Stress-Strain Relationship of LFC-ES7.5-0.56

Table 5.7 shows the 90-day compressive toughness for LFC-CTR and LFC-ES7.5. The compressive toughness of LFC specimens are computed by integrating the vertical deformation's curve's trend line equation which obtained from Figures 5.8 and 5.9. The compressive toughness value indicates the energy that can be absorbed by a specimen before it fails in compression. For 90 days of curing period, the compressive toughness values of LFC-CTR and LFC-ES7.5 are 5.67×10^{14} J/m ³ and 2.11×10^{15} J/m ³respectively.

In general, adding of eggshell powder enhanced the compressive toughness than that of LFC specimens with 100 % pure cement. LFC-ES7.5 able to withstand more loads with higher strain than that of LFC-CTR.

Table 5.7: Compressive Toughness for LFC-CTR and LFC-ES7.5 at 90 Days of Curing Period

Curing Period	Specimens Series No.	Curves' Trend Line Equation	R^2	Maximum Compressive Stress, σ (MPa)	Corresponding Vertical Strain, $\varepsilon \times 10^{-6}$ (mm/mm)	Total Compressive Toughness (J/m^3)
90-Day	LFC-CTR-0.56	$\sigma = 83074\varepsilon^2 + 985.17\varepsilon - 0.1254$	0.9891	2.99	2736	5.67×10^{14}
	LFC-ES7.5-0.56	$\sigma = 39339\varepsilon^2 + 674.11\varepsilon - 0.159$	0.9472	4.70	5440	2.11×10^{15}

5.8 Performance Index

Performance index is a parameter that used to obtain the strength of concrete per 1000 kg/m^3. Theoretically, a higher density of concrete will result in a higher compressive strength. In order to obtain more accurate and reliable results, performance index method has been adopted.

5.8.1 Performance Index of Compressive Strength

The performance indexes of compressive strength for LFC-CTR and LFC-ES7.5 are illustrated in Figure 5.10.

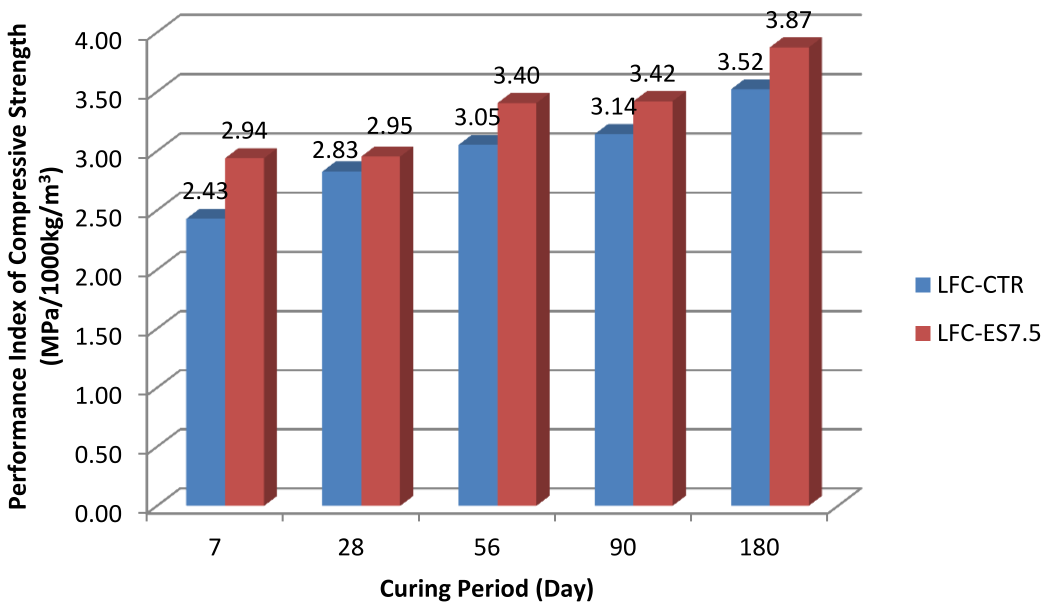

Figure 5.10: Performance Index of Compressive Strength from 7 to 180 Days of Curing Periods for LFC-CTR and LFC-ES7.5

Figure 5.10 shows the performance index of compressive strength for LFC-CTR and LFC-ES7.5 for each curing period ranging from 7 to 180 days of ages. Based on Figure 5.10, it is clearly shown that the performance index of compressive strength for both LFC-CTR and LFC-ES7.5 increased throughout the curing periods which in turn proving the trends of compressive strength development. The highest performance index of compressive strength achieved by LFC-CTR and LFC-ES7.5

are 3.52 MPa per 1000 kg/m^3 and 3.87 MPa per 1000 kg/m^3 respectively at 180 days of curing period. Apart from that, the performance indexes of compressive strength of LFC-ES7.5 are generally higher than that of LFC-CTR for all curing periods.

5.8.2 Performance Index of Splitting Tensile Strength

The performance indexes of splitting tensile strength for LFC-CTR and LFC-ES7.5 are illustrated in Figure 5.11.

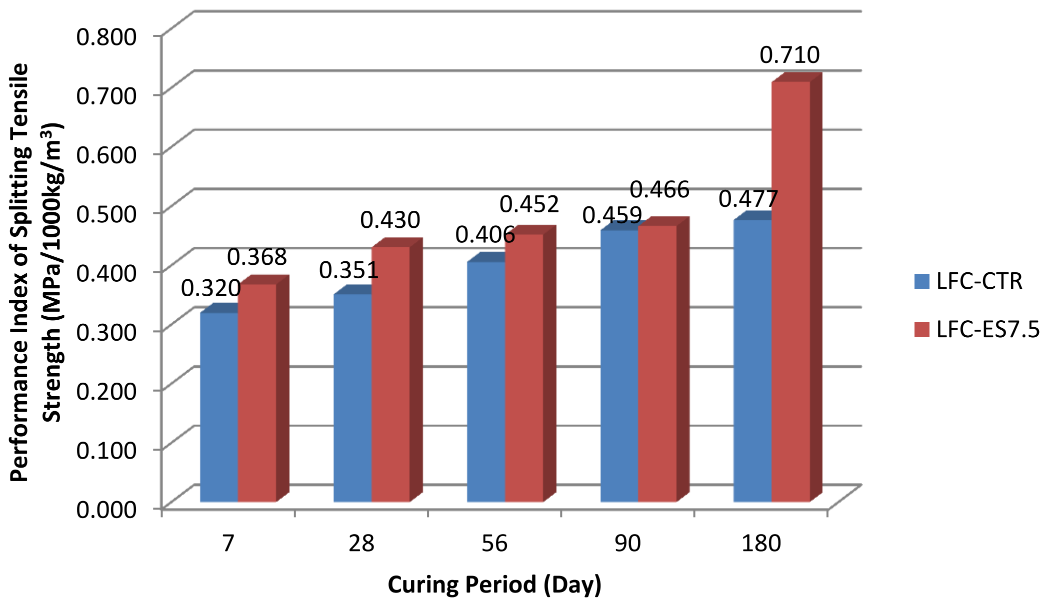

Figure 5.11: Performance Index of Splitting Tensile Strength from 7 to 180 Days of Curing Periods for LFC-CTR and LFC-ES7.5

Figure 5.11 presents the performance index of splitting tensile strength for LFC-CTR and LFC-ES7.5 for each curing period ranging from 7 to 180 days of ages. Based on Figure 5.11, it is clearly shown that the performance index of splitting tensile strength for both LFC-CTR and LFC-ES7.5 increased throughout the curing periods. This had proven that the trend of splitting tensile strength development which is increasing throughout the curing periods. The highest performance indexes of splitting tensile strength achieved by LFC-CTR and LFC-ES7.5 are 0.477 MPa per 1000 kg/m^3 and 0.710 MPa per 1000 kg/m^3 respectively at 180 days of curing period. Other than that, the performance indexes of splitting tensile strength of LFC-ES7.5 are generally higher than that of LFC-CTR for all curing periods.

5.8.3 Performance Index of Flexural Strength

The performance indexes of flexural strength for LFC-CTR and LFC-ES7.5 are illustrated in Figure 5.12.

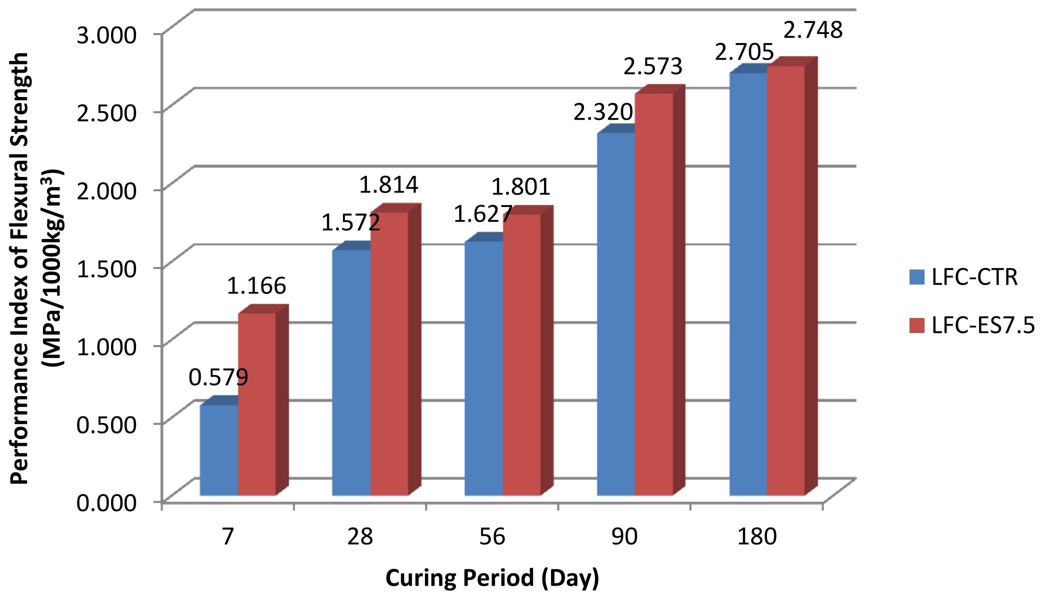

Figure 5.12: Performance Index of Flexural Strength from 7 to 180 Days of Curing Periods for LFC-CTR and LFC-ES7.5

Based on Figure 5.12, it is clearly shown that the performance indexes of flexural strength for both LFC-CTR and LFC-ES7.5 increased throughout the curing periods. As similar to the case in splitting tensile strength, the performance index method for flexural strength had proven that the trend of flexural strength development which is increasing throughout the curing periods. The highest performance indexes of flexural strength achieved by LFC-CTR and LFC-ES7.5 are 2.705 MPa per 1000 kg/m^3 and 2.748 MPa per 1000 kg/m^3 respectively at 180 days of curing period. Besides that, the performance indexes of flexural strength of LFC-ES7.5 are generally higher than that of LFC-CTR for all curing periods.

5.9 Summary

Eggshell powder in lightweight foamed concrete as partial cement replacement material plays important role in enhancing its engineering properties in terms of compressive, splitting tensile and flexural strengths, Poisson's ratio as well as compressive toughness.

LFC-ES7.5 obtained highest compressive strength and performance index at 180 days of age which are 5.16 MPa and 3.87 MPa per 1000 kg/m^3 respectively compared to that of LFC-CTR. Generally, specimens of LFC-ES7.5 have higher compressive strength than that of LFC-CTR. This is due to the calcium carbonate content possessed by eggshell powder could help in accelerating the hydration of tri-calcium silicate which responsible for the early strength of concrete. Besides that, calcium carbonate also plays the role as inert filler which helps to fill up the capillary pores within concrete and results in a less porous microstructure, thus increasing the compressive strength of concrete.

For splitting tensile and flexural strengths, both have the similar trend where strengths are directly proportional to the curing periods. The performance indexes of splitting tensile and flexural strengths were increasing throughout the curing periods. LFC-ES7.5 obtained highest splitting tensile strength and performance index at 180 days of age which are 1.004 MPa and 0.710 MPa per 1000 kg/m^3 respectively. For flexural strength, LFC-ES7.5 obtained highest strength and performance index at 180 days of age which are 3.855 MPa and 2.748 MPa per 1000 kg/m^3 respectively.

In term of Poisson's ratio, LFC-ES7.5 possesses higher Poisson's ratio than that of LFC-CTR at 90 days of age, which is 0.214. Nevertheless, LFC-ES7.5 possesses higher compressive strength with higher deformation at horizontal axis as compared to that of LFC-CTR. Generally, static modulus of elasticity of concrete will increase with the incremental of compressive strength. For static modulus of elasticity, LFC-ES7.5 possesses higher value than that of LFC-CTR at 90 days of age, which is 698 MPa. In term of compressive toughness, LFC-ES7.5 serves a better performance than that of LFC-CTR. LFC-ES7.5 possesses the highest compressive toughness at 90 days of curing period which recorded at 2.11×10^{15} J/m ^{3} as compared to LFC-CTR. This shows that incorporation of eggshell in the LFC helped in the durability of LFC specimens. The denser microstructural images of LFC-ES7.5 compared to that of LFC-CTR further justifies the statement.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Based on the laboratory results obtained, the following conclusions can be drawn corresponding to the respective objectives that listed out in Chapter 1 of this study.

The first objective of this study is to produce lightweight foamed concrete with density in the range of 1250 – 1350 kg/m^3. This was achieved as the densities of two types of lightweight foamed concrete prepared namely LFC-CTR and LFC-ES7.5 were in the range of the desired density as tabulated in Table 4.2 and Table 4.5 respectively.

The second objective is to identify the optimal water to cement ratio which give the highest performance index for both LFC-CTR and LFC-ES7.5. This was achieved by screening of trial mixes results, where the optimal water to cement ratio for both LFC-CTR and LFC-ES7.5 was determined as 0.56.

The third objective is to assess the effect of eggshell on fresh properties of lightweight foamed concrete in terms of workability, consistency and stability. Apparently, LFC-ES7.5 possesses lower workability than that of LFC-CTR. For consistency and stability, both values of LFC-CTR and LFC-ES7.5 are nearly to unity. The eggshells didn’t bring any significant effect on the both properties.

The last objective is to study the effect of eggshell as part of cement replacement materials on engineering properties of lightweight foamed concrete in terms of compressive, splitting tensile and flexural strengths, Poisson's ratio as well as compressive toughness. Incorporation of eggshell powder into lightweight foamed concrete has increased the compressive, splitting tensile and flexural strengths, Poisson's ratio as well as compressive toughness compared to those of the control mix.

6.2 Recommendations

The study of lightweight foamed concrete with eggshell as cement replacement material is still very new and limited in this field. In order to improve and enhance this research work in future, there are few aspects and suggestion need to be taken into consideration for further improvement:

1. Use more water to cement ratios with smaller interval for trial mix casting to obtain optimal water to cement ratio in order to have a more accurate result.
2. Different curing method for the concrete specimens and study the impact on other engineering properties such as initial surface absorption test (ISAT), thermal conductivity, and sound insulation etc.
3. Cast concrete specimen by replacing cement content with higher percentage of eggshell powder to study the strength development of lightweight foamed concrete incorporated by eggshell powder.

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APPENDICES

APPENDIX A: Consumption of Livestock Products in Malaysia, 2004 - 2013

MALAYSIA : PENGGUNAAN HASILAN TERNAKAN, 2004-2013

Malaysia : Consumption of Livestock Products, 2004-2013

KOMODITI *Commodity*	WILAYAH *Region*	2004	2005	2006	2007	2008	2009	2010	2011	2012^P	2013^E
DAGING LEMBU/KERBAU	**S. Malaysia**	139,496	127,956	135,219	134,568	126,677	141,666	145,412	158,111	161,089	169,066
Beef	**Sabah**	2,683	7,544	4,604	5,867	4,736	2,471	4,885	5,039	7,588	6,188
(M. Tan/M. Ton)	**Sarawak**	6,367	3,480	6,550	4,297	4,116	5,119	4,105	4,239	5,138	5,581
Jumlah	*Total*	**148,546**	**138,980**	**146,373**	**144,732**	**135,529**	**149,256**	**154,402**	**167,388**	**173,815**	**180,835**
DAGING KAMBING/BEBIRI	**S. Malaysia**	14,631.0	16,336.0	17,129.0	16,731.7	17,961.6	18,408.2	18,646.6	18,061.8	23,132.0	25,709.0
Mutton	**Sabah**	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
(M. Tan/M. Ton)	**Sarawak**	441.0	637.0	671.0	766.5	1,051.4	901.3	1,022.7	1,136.8	1,391.0	1,281.0
Jumlah	*Total*	**15,072.0**	**16,973.0**	**17,800.0**	**17,498.2**	**19,013.0**	**19,309.4**	**19,669.3**	**19,198.6**	**24,523.0**	**26,990.0**
DAGING BABI	**S. Malaysia**	160,756	180,505	176,813	160,957	159,194	172,186	200,924	199,919	201,983	183,539
Pork	**Sabah**	8,593	9,268	9,016	8,237	9,109	7,802	7,941	8,083	8,082	8,802
(M. Tan/M. Ton)	**Sarawak**	31,710	31,087	33,436	33,494	30,034	31,965	36,525	36,270	38,345	34,250
Jumlah	*Total*	**201,059**	**220,860**	**219,265**	**202,688**	**198,337**	**211,953**	**245,390**	**244,272**	**248,410**	**226,590**
DAGING AYAM/ITIK	**S. Malaysia**	762.54	679.36	685.34	926.54	993.96	1,029.09	1,104.57	1,142.77	1,201.85	1,209.60
Poultry Meat	**Sabah**	54.56	57.51	87.28	60.57	58.23	50.03	49.99	47.78	62.38	80.55
(`000 M. Tan)	**Sarawak**	43.29	48.79	56.11	61.47	65.71	67.78	72.89	76.06	84.40	83.55
Jumlah	*Total*	**860.39**	**785.66**	**828.73**	**1,048.59**	**1,117.90**	**1,146.90**	**1,227.45**	**1,266.61**	**1,348.63**	**1,373.69**
TELUR AYAM/ITIK *	**S. Malaysia**	5,393	6,072	5,921	6,001	6,093	6,711	7,249	7,613	7,902	7,985
Chicken/Duck Eggs	**Sabah**	467	142	490	418	455	469	554	562	543	534
(Juta Biji/Mil. Eggs)	**Sarawak**	614	580	696	738	752	707	768	805	909	884
Jumlah	*Total*	**6,474** **** 388**	**6,793** **** 408**	**7,107** **** 426**	**7,157** **** 429**	**7,300** **** 438**	**7,887** **** 473**	**8,572** **** 514**	**8,980** **** 539**	**9,354** **** 561**	**9,403** **** 564**
SUSU	**S. Malaysia**	1,281.35	884.45	957.84	870.17	634.63	698.91	778.88	528.32	791.77	838.05
Milk	**Sabah**	16.20	7.99	15.22	16.37	14.37	7.92	8.13	8.34	12.38	12.43
(Juta Liter/Mil. Litres)	**Sarawak**	2.92	2.62	2.75	2.51	1.83	2.00	2.22	1.52	3.51	2.42
Jumlah	*Total*	**1,300.47**	**895.06**	**975.81**	**889.05**	**650.83**	**708.83**	**789.23**	**538.18**	**807.66**	**852.89**

P : Sementara *(Provisional)*
E : Anggaran *(Estimate)*

n.a : Tiada maklumat *(Not available)*
** : ('000) M.Tan

* Anggaran purata berat telur ayam/itik = 60 gm/biji
** Estimated average weight of chicken/duck egg = 60 gm/egg*

Figure A1: Consumption of Livestock Products in Malaysia, 2004 – 2013 (DVS, 2013)

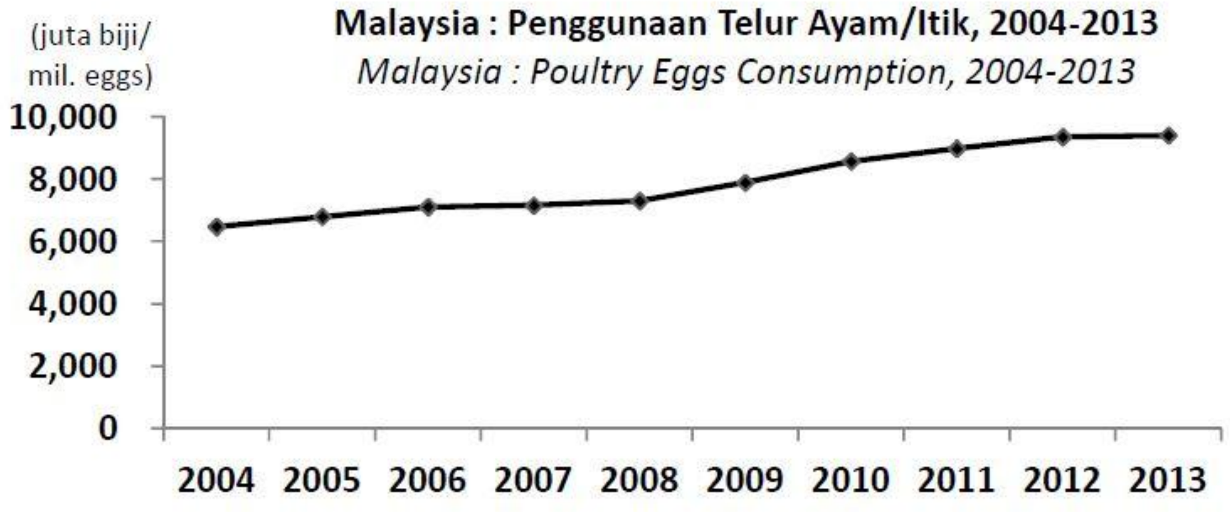


Figure A2: Poultry Eggs Consumption in Malaysia, 2004 – 2013 (DVS, 2013)

APPENDIX B: Compressive Strength of Various Types LFC Specimens

Curing Period (Days)	Mix	Oven Dry Density (kg/m^3)	Bulk Hardened Density (kg/m^3)	Compressive Strength (MPa)	Performance Index ($MPa/1000kg/m^3$)
7	LFC-CTR	1255	1473	3.58	2.43
	LFC-ES7.5	1271	1383	4.07	2.94
28	LFC-CTR	1166	1369	3.87	2.83
	LFC-ES7.5	1253	1358	4.17	2.95
56	LFC-CTR	1195	1401	4.28	3.05
	LFC-ES7.5	1160	1300	4.45	3.40
90	LFC-CTR	1291	1344	4.30	3.14
	LFC-ES7.5	1238	1366	4.67	3.42
180	LFC-CTR	1365	1445	5.10	3.52
	LFC-ES7.5	1172	1328	5.16	3.87

APPENDIX C: Splitting Tensile Strength of Various Types LFC Specimens

Curing Period (Days)	Mix	Oven Dry Density (kg/m^3)	Bulk Hardened Density (kg/m^3)	Splitting Tensile Strength (MPa)	Performance Index ($MPa/1000kg/m^3$)
7	LFC-CTR	1256	1324	0.431	0.320
	LFC-ES7.5	1362	1420	0.522	0.368
28	LFC-CTR	1171	1317	0.461	0.351
	LFC-ES7.5	1201	1395	0.600	0.430
56	LFC-CTR	1097	1373	0.564	0.406
	LFC-ES7.5	1111	1264	0.579	0.452
90	LFC-CTR	1164	1348	0.619	0.459
	LFC-ES7.5	1338	1443	0.673	0.466
180	LFC-CTR	1185	1386	0.661	0.477
	LFC-ES7.5	1286	1417	1.004	0.710

APPENDIX D: Flexural Strength of Various Types LFC Specimens

Curing Period (Days)	Mix	Oven Dry Density (kg/m^3)	Bulk Hardened Density (kg/m^3)	Flexural Strength (MPa)	Performance Index ($MPa/1000kg/m^3$)
7	LFC-CTR	1083	1211	0.692	0.579
	LFC-ES7.5	1168	1278	1.491	1.166
28	LFC-CTR	1057	1292	2.028	1.572
	LFC-ES7.5	1069	1212	2.205	1.814
56	LFC-CTR	1079	1344	2.226	1.627
	LFC-ES7.5	1095	1200	2.161	1.801
90	LFC-CTR	1174	1199	2.712	2.320
	LFC-ES7.5	1153	1298	2.743	2.573
180	LFC-CTR	1292	1392	3.776	2.705
	LFC-ES7.5	1239	1401	3.855	2.748

APPENDIX E: Porosity and Water Absorption of Various Types LFC Specimens

Curing Period (Days)	Mix	Oven-Dried Weight, W_{dry} (kg)	Saturated Surface Dry Weight, W_{sat} (kg)	Weight of Specimen in Water, W_{wat} (kg)	Porosity (%)	Water Absorption (%)
7	LFC-CTR	1.14	1.47	0.99	68.88	29.08
	LFC-ES7.5	1.24	1.69	1.05	69.39	35.71
28	LFC-CTR	1.26	1.60	1.02	57.72	26.53
	LFC-ES7.5	1.15	1.46	1.00	67.31	27.15
56	LFC-CTR	1.30	1.56	0.95	42.69	20.00
	LFC-ES7.5	1.18	1.48	1.00	60.92	24.91
90	LFC-CTR	1.34	1.56	0.95	35.20	15.81
	LFC-ES7.5	1.28	1.58	1.00	52.75	23.87
180	LFC-CTR	1.38	1.59	0.97	35.06	15.74
	LFC-ES7.5	1.25	1.55	0.96	50.88	23.81

APPENDIX F: Graph of Porosity and Water Absorption of Various Types LFC Specimens

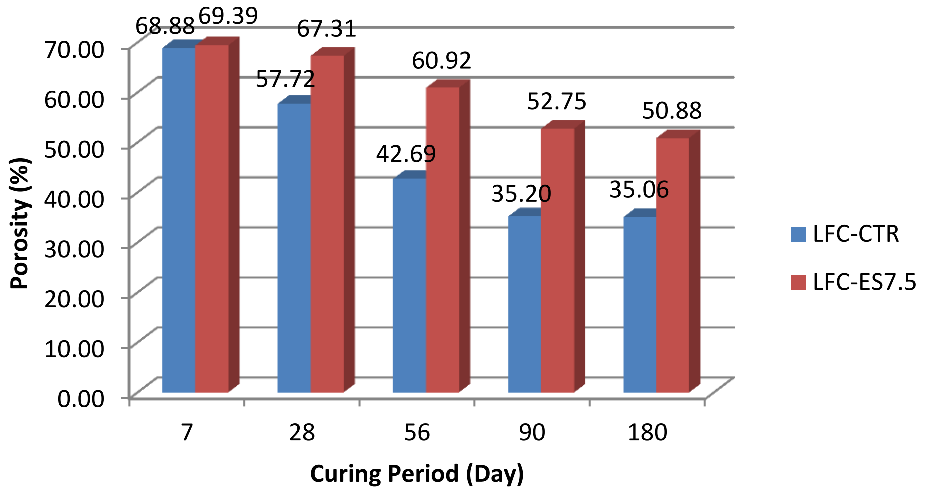


Figure F1: Porosity of 7, 28, 56, 90 and 180 Days of Curing Periods for LFC-CTR and LFC-ES7.5

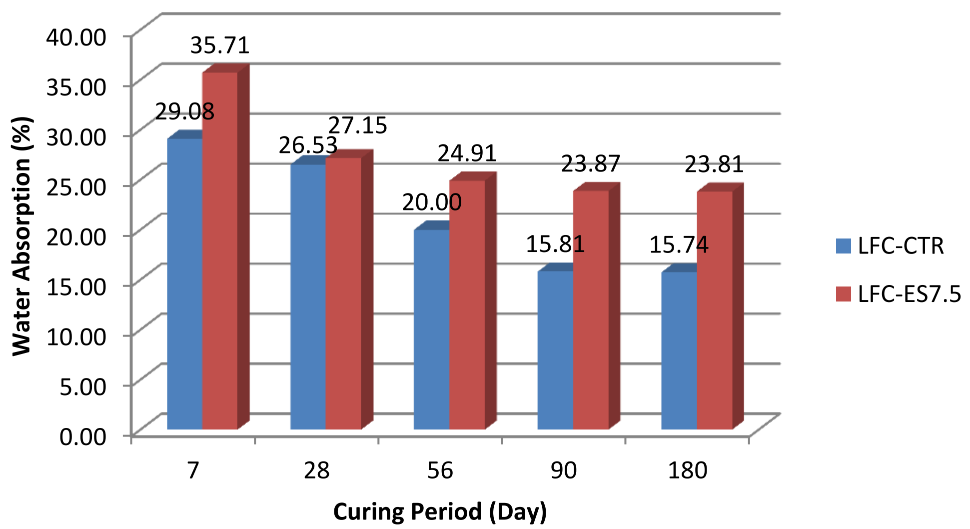
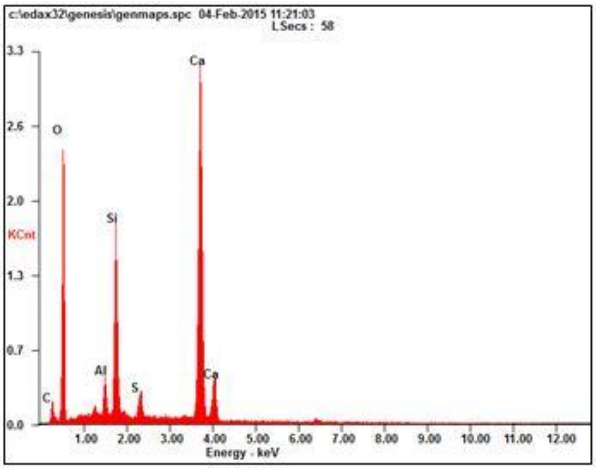


Figure F2: Water Absorption of 7, 28, 56, 90 and 180 Days of Curing Periods for LFC-CTR and LFC-ES7.5

APPENDIX G: Elemental Composition Analysis using Energy-Dispersive X-Ray Spectroscopy (EDS)



Element	Wt%	At%
CK	00.89	02.08
OK	21.00	37.04
AlK	02.37	02.48
SiK	15.47	15.55
SK	02.34	02.06
CaK	57.93	40.79
Matrix	Correction	MThin

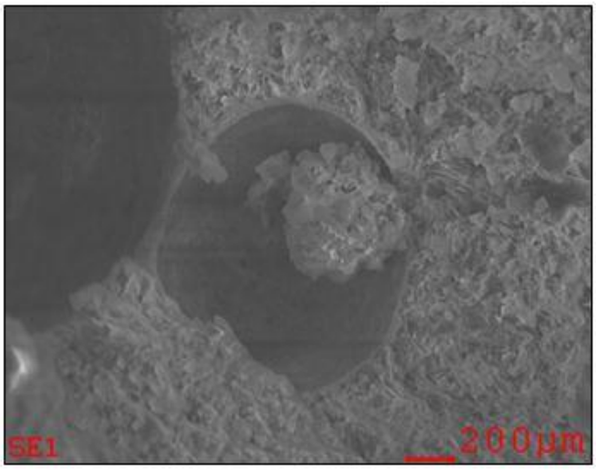
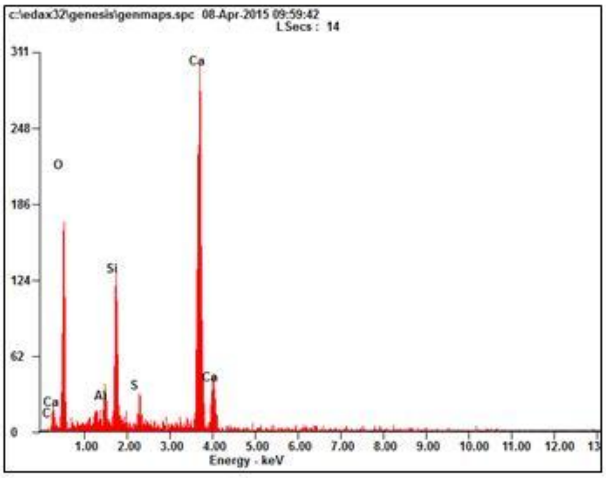


Figure G1: Elemental Composition Analysis of Chemical Characterization of LFC-CTR at 90 Days of Curing Period



Element	*Wt%*	*At%*
CK	00.84	02.00
OK	20.07	36.09
AlK	02.29	02.44
SiK	12.39	12.70
SK	02.85	02.56
CaK	61.56	44.20
Matrix	Correction	MThin

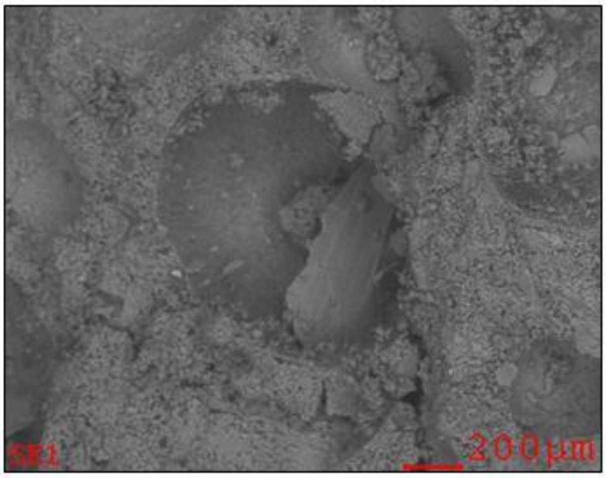


Figure G2: Elemental Composition Analysis of Chemical Characterization of LFC-ES7.5 at 90 Days of Curing Period

APPENDIX H: Microstructural Analysis using Scanning Electron Microscope (SEM)

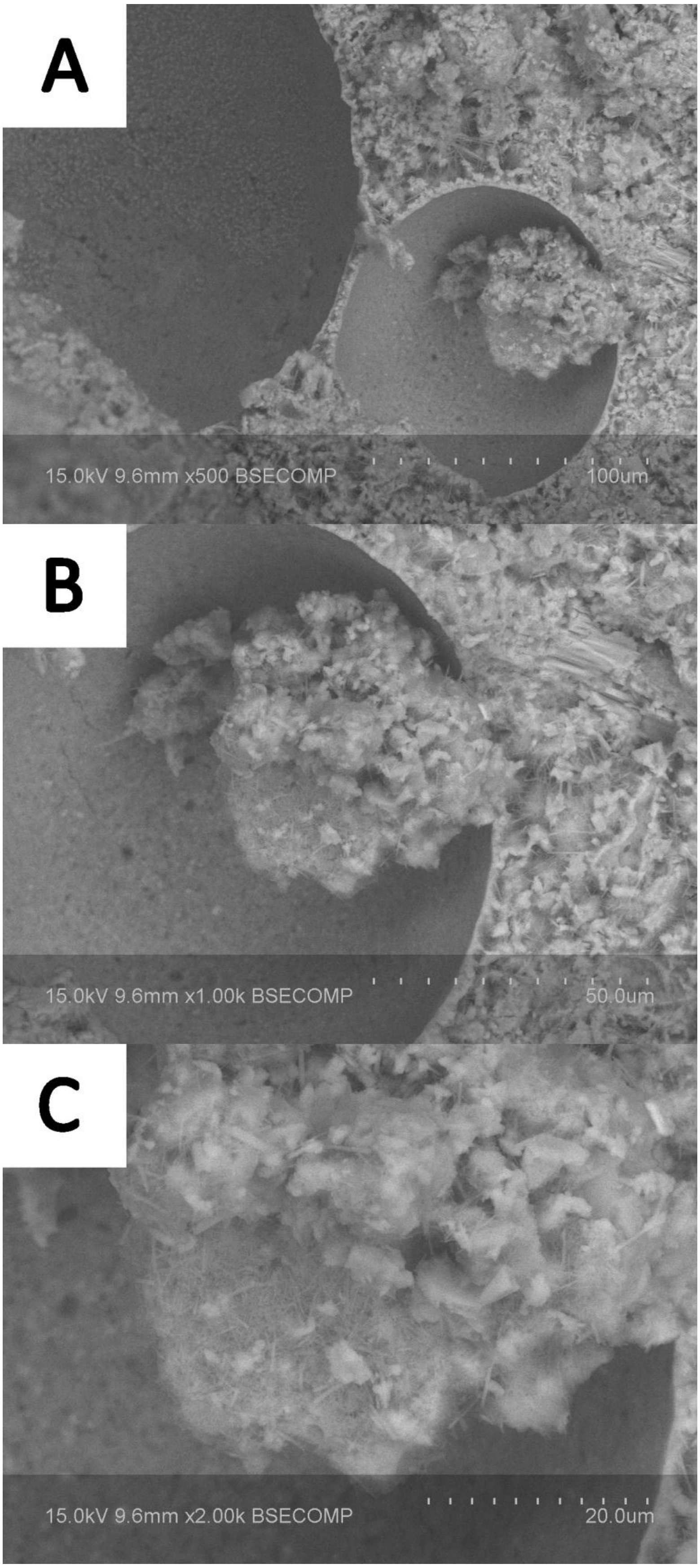


Figure H1: Microstructural Images of LFC-CTR at 180 Days of Curing Period: (A) 500x, (B) 1000x, (C) 2000x of magnification

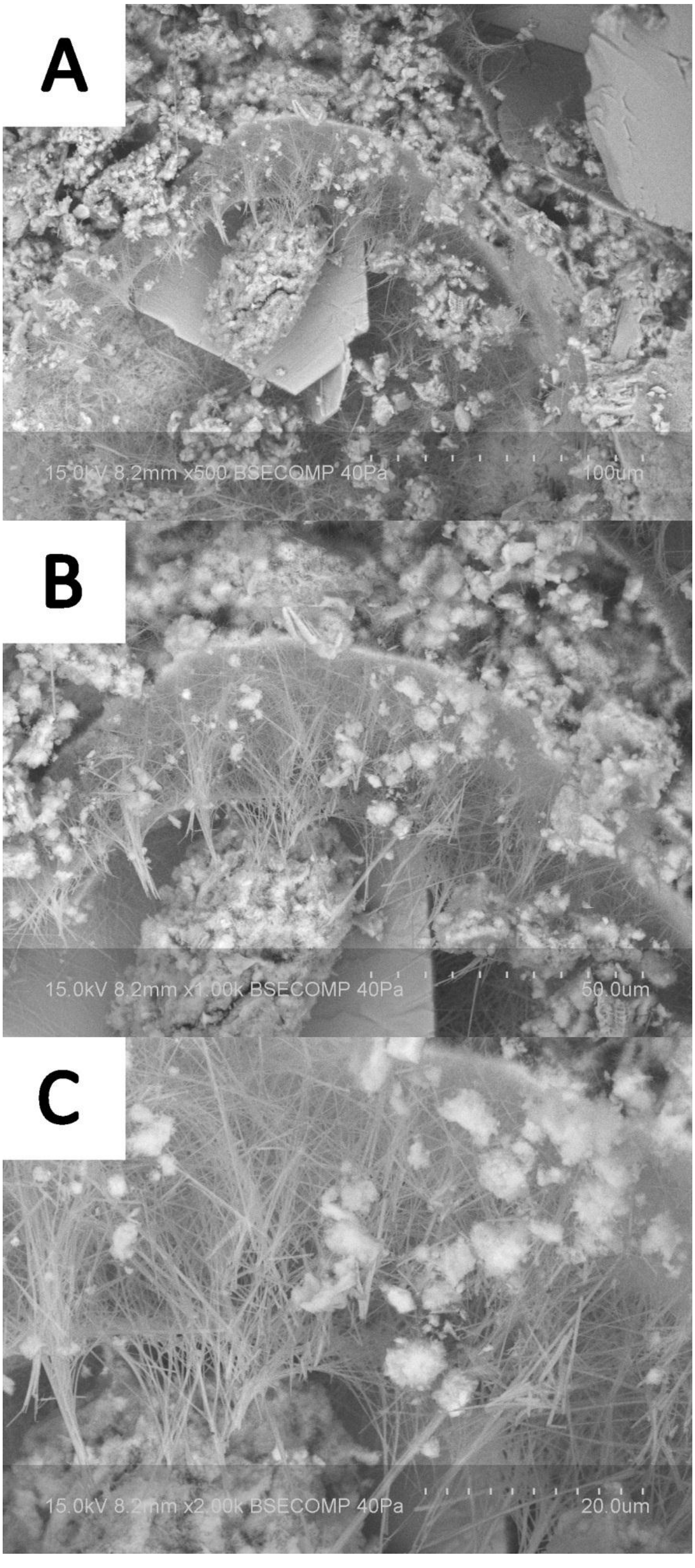


Figure H2: Microstructural Images of LFC-ES7.5 at 180 Days of Curing Period: (A) 500x, (B) 1000x, (C) 2000x of magnification