ENGINEERING PROPERTIES OF LIGHTWEIGHT FOAMED CONCRETE WITH 10% EGGSHELL AS PARTIAL CEMENT REPLACEMENT MATERIAL

GOH SHENG MENG

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

Lee Kong Chian Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

MAY 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.

Signature : ________________________

Name : Goh Sheng Meng

ID No. : 10UEB03839

Date : 13/4/2015

APPROVAL FOR SUBMISSION

I certify that this project report entitled **"ENGINEERING PROPERTIES OF LIGHTWEIGHT FOAMED CONCRETE WITH 10% EGGSHELL AS CMENT REPLACEMENT MATERIAL"** was prepared by **GOH SHENG MENG** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Civil Engineering at Universiti Tunku Abdul Rahman.

Approved by,

Signature : ______________________________

Supervisor : Ir. Dr. LIM SIONG KANG

Date : ______________________________

Specially dedicated to

my beloved grandparents, mother and father.

ACKNOWLEDGEMENTS

I would like to thank everyone who had contributed to the successful completion of this project. I would like to express my gratitude to my research supervisor, Ir. Dr. Lim Siong Kang for his invaluable advice, guidance and his enormous patience throughout the development of the research.

In addition, I would also like to express my gratitude to the lab officers, in which they always provide useful information and taught me useful skills throughout my research period. Other than that, they are very friendly and corporative. A word of gratitude is extended to my fellow partners, Ervin Tiu Shan Khai and Teng Kah Yew, which had provide me a lot of help throughout my research period. Lastly, I'm thankful to receive countless blessing from my friends and family who always been there to support me whenever I needed and provide me the source of inspiration to finished the study

ENGINEERING PROPERTIES OF LIGHTWEIGHT FOAMED CONCRETE WITH 10% EGGSHELL AS PARTIAL CEMENT REPLACEMENT MATERIALS

ABSTRACT

Malaysia is one of the largest egg consumption countries in the world. Malaysians are consuming 20 million eggs everyday which averaging 320 eggs per person per year. The waste produced by the disposal of eggshell is tremendous, which is one of the problems faced by the industries. Therefore, waste disposal problem can be solved when eggshell is being recycled by incorporating eggshell into production of lightweight foamed concrete (LFC). This study is aimed to investigate the effect of eggshell powder on the engineering properties of lightweight foamed concrete with the density of 1300kg/m^3 with the tolerance of ±50 kg/m^3 in terms of strength properties. Fresh density, flow table drop, average inverted slump diameter, stability and consistency of the concrete were determined during trial mixes. The optimal water to cement ratio was chosen based on the comparison of performance index between trial mix of control mix (LFC-CTR) and trial mix of lightweight foamed concrete with 10% replacement of cement as eggshell (LFC-ES10%). The optimum water to cement ratio was then used to study the development of engineering properties for 7, 28, 56, 90 and 180 days curing period between LFC-CTR and LFC-ES10%. All the specimens were water cured to the desired period prior for testing. The results from this study showed that by incorporating 10% eggshell powder as partial cement replacement materials had increased the compressive, splitting tensile and flexural strength as well as Poisson’s ratio and compressive toughness.

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LIST OF SYMBOLS / ABBREVIATIONS

A	cross-sectional area, mm^2
d	diameter of specimen, mm
f	d
h	depth of specimen, mm
l	length of specimen, mm
P	maximum load at failure, N
PI	performance index, MPa per 1000 kg/m^3
R	flexural strength, MPa
T	splitting tensile strength, MPa
C-S-H	Calcium Silicate Hydrate
OPC	Ordinary Portland Cement
LFC-CTR	Control mix (LFC with 100 % sand as filler)
LFC-ES10%	lightweight foamed concrete with 10% eggshell replacement as part of cement.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

This report shows the study of the possibility of eggshell powder as a replacement for part of the cement in lightweight foamed concrete (LFC). The main purpose of this study is to investigate the development of engineering properties after 10% of eggshell powder is used as cement replacement. The most basic definition of light weight foamed concrete is that it is 'mortar with bubbles in it.' The air content of foamed concrete can be up to 75% by volume. The dry density of lightweight foamed concrete can be in a range of 300kg/m^3 to 1850kg/m^3 (Neville, 2006). Lightweight foamed concrete is a very versatile and multi-purposes material. It has excellent resistance to water and frost and provides a high level of both sound and thermal insulation.

Lightweight foamed concrete is now becoming a favourite material to be used in construction industry. This is because by the term lightweight explain that it does not impose large loadings, excellent fire resisting material, low water adsorption over time, excellent sound and thermal insulation and many more. There are various application of lightweight foamed concrete, for example, roof insulation material, void filling material, lightweight foamed concrete blocks, fire breaks and etc.

Eggshell is a very common waste that is generated in a large amount in daily life. According to Lee (2006), Malaysia is one of the largest egg consumption countries in the world. Malaysian consumes a total of 20 million eggs daily. With the large amount of eggs being consume, addition to improper disposal procedure of eggshell will contributes to severe environmental hazard. This is because the eggshell with the attached protein membrane will attract vermin and promote bacteria growth. Other than that, improper eggshell disposal will attract worms and rats due to the protein membrane. Eggshell wastes are often used as feed to animals, fertilizer to soil as well as cosmetic product by processing protein membrane.

Recent years, many researchers are trying to utilize eggshell waste into innovative technology in order to minimized environment issues caused by eggshell waste as well as minimizing material cost. However, research on the application of eggshell in civil engineering industry does not seem to be popular. There are researches about partial replacement of fine aggregate with eggshell (ES) and Snailshell (SS) in the production of highway concrete structures. (Amusat, *et al*., 2007), Soil cement bricks incorporated with eggshell waste. (Mateus, *et al*., 2013), and Suitability of Eggshell Stabilized Lateritic Soil as Subgrade Material for Road Construction (Olarewaju, *et al*., 2011.). The reason eggshell is used as a replacement material is due to eggshell is rich in $CaCO_3$. Other than that, fine grain of eggshell powders is a good accelerator for cement –bound materials. The chemical composition of eggshell is reported as 94% calcium carbonate, 1% magnesium carbonate, 1% calcium phosphate and 4% organic matter. (Hunton, 2005).

1.2 Problem Statement

According to report by Lee, (2006), Malaysia is one of the largest egg consumption countries in the world. In this case, it is noticeable the waste produce by eggshells alone is extremely tremendous. According to Malaysia Veterinary Department, (2013) the total amount of waste produced by eggshell at 2012 is 9354 million eggshells. According to assumption made by Malaysia Veterinary Department, the number of waste eggshells produced is about 9403 million eggshells. So, by following this trend, the amount of waste eggshells produced will be estimated to increase at year 2014. Statistic of waste eggshells statistics can be referred at appendix.

Lightweight foamed concrete possesses a lot of benefits when it is used as non-load bearing member of structure. This is mainly due to the lightweight properties of lightweight foamed concrete which it does not impose large load to the structure. Hence, by implying lightweight foamed concrete as non-load bearing member, the overall load of structure can be reduced. (Retrieved from: http://buildotechindia.com/foamed_concrete_and_its_applications/)

Hence, by incorporating eggshell as partial cement replacement, eggshell waste can then be potentially reduced. Lesser waste produced will means lesser pollution and this can save the environment.

1.3 Objectives of Study

The objectives of this study are:

- To produce lightweight foamed concrete with fresh and hardened density in a range of 1250kg/m^3 to 1350kg/m^3.
- To obtain the optimal water to cement ratio for LFC-CTR and LFC-ES10.
- To study the effect of eggshell as part of cement replacement on fresh properties of concrete mix in terms of inverted slump value, consistency and stability.
- To study the effect of eggshell powder as partial cement replacement on engineering properties of lightweight foamed concrete in terms of compressive, flexural and splitting tensile strengths as well as Poisson’s ratio and compressive toughness.

1.4 Scope of Study

This study mainly focus on the effect of 10% cement replacement by eggshell in lightweight foamed concrete based on compressive strength, splitting tensile, flexural strength, Poisson's ratios. Material preparation and casting procedures was done by reference of ASTM standard and requirement. Compressive strength was obtained by testing cubic specimen, splitting tensile strength was obtained by testing cylindrical specimen and flexural strength was obtained by testing prismatic specimen.

Optimum water to cement ratio for LFC-CTR and LFC-ES10 were obtained from trial mixes result. The range of water to cement ratio used during trial mixes was 0.52 to 0.64 with an interval of 0.04. Result of compressive strength and performance index were used to determine the optimum water to cement ratio based on 7 days and 28 days of curing period.

The optimum water to cement ratio of both LFC-CTR and LFC-ES10 were then be used to cast other specimens in order to obtain compressive strength, splitting tensile strength, flexural strength, Poisson's ratio and compressive toughness for 7 days, 28 days, 56 days, 90 days and 180 days of curing ages.

1.5 Significance of Study

The significance of this study is to investigate the possibility of enhancing the engineering properties of lightweight foamed concrete by introducing 10% of eggshell as cement replacement in lightweight foamed concrete. This research produced a mix proportion in accordance of the production of lightweight foamed concrete incorporated with eggshell powder.

LFC is already an innovative product common to construction sector due to a low density ranging from 1000 to 1600kg/m^3. A low density concrete results on a decrease in total weight of a structure. Deduction of total weight can reduce the needs of reinforcement and thus result in a more economical project. Other than money savings, LFC also provide better fire protection, thermal, sound insulations, higher workability and easier to be produced compared to normal weight concrete. (Lim, *et al*., 2013).

The reason of introducing eggshells into lightweight foamed concrete is to minimize the environment impact caused by improper disposal of eggshells. Other than that, by partial replacement of cement by eggshell powder can reduce the material cost as the mix requires less cement.

1.6 Layout of Report

This report consists of 6 chapters. Chapter one present the introduction of early study, problem statement, objectives of study, scope of study, significance of study and layout of report.

Chapter two discusses about the review on materials used and properties of lightweight foamed concrete.

Chapter three discusses about the methodologies used in this study. In this chapter, method of calculating mix proportion, the preparation of materials, mixing procedures as well as various tests regarding this study were discussed.

Chapter four presents the discussion of the results from trial mixes. The optimum water to cement ratios for LFC-CTR and LFC-ES10% were determined based on the results obtained from the trial mixes.

Chapter five mainly discusses about the results obtained from 7 days, 28 days, 56 days, 90 days and 180 days LFC-CTR and LFC-ES10% specimens in terms of compressive, splitting tensile and flexural strength, Poisson’s ratio and compressive toughness.

Chapter six concludes the study, some recommendations are given in order to improve the further studies. Conclusions are drawn based on the results obtained in laboratory.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Lightweight foamed concrete is a product of ordinary Portland cement (OPC), river sand, eggshell powder, foam and water. By mechanically introducing foam into lightweight concrete, air can be entrap into the concrete resulting a lighter concrete, excellent sound and thermal insulation and excellent freeze thaw resistance compared to normal or heavy weight concrete. (Mydin, *et al*., 2011).

According to buildotechindia.com, foamed concrete had increased its fame in the construction industry. This is because foamed concrete can provide benefits in terms of cost and performance when compared to traditional building materials.

Eggshell usage in civil engineering field had seen to be studied by numerous researchers. Those researches include replacement of fine aggregate with eggshell in highway concrete structure, eggshell as a material to stabilized lateritic soil as subgrade material and as a raw material for wall tile production.

2.3 Advantages of Lightweight Foamed Concrete

The advantages of lightweight foamed concrete in different prospect had made lightweight foamed concrete much more preferable than normal weight concrete. For an example, non-load bearing component of lightweight foamed concrete definitely out run normal weight concrete in terms of lightness due to the lower density of lightweight foamed concrete. Other than that, lightweight foamed concrete had made concrete casting much more easy. This is because lightweight foamed concrete does not require compaction or vibration. The higher workability offers ease of transporting cement paste just by pouring or pumping. According to the research from Mydin, (2011) lightweight foamed wall panel with density of 1400kg/m^3 requires only 67.4mm to achieve a 120 minutes fire resistance rating. Other than that, thickness required of lightweight foamed panel decreases with the decrease of density. Lastly, lightweight foamed concrete also highly recommended to be used as residential partition wall due to it excellency in insulating sound.

2.4 Properties of Lightweight Foamed Concrete

Properties of lightweight foamed concrete can be categorized as fresh properties and hardened properties. Fresh properties discusses about fresh density, workability, consistency as well as stability of fresh cement paste. On the other hand, hardened properties include hardened density, compressive strength, splitting tensile strength, flexural strength, Poisson’s ratio, porosity test and water absorption test.

2.4.1 Fresh Properties

Workability of concrete is an important aspect because it is one of the physical parameters that will affect the strength of concrete and durability of concrete. Other than that, it will vary the labor cost and the finished appearance of concrete.

Consistency is a parameter that indicates the ratio of mixed water to dry materials. Hence, consistency will affect the workability of cement paste. (Koehler and Fowler, 2004)

Foam that is added into the cement paste must be stable and firm so that those foam can withstand the pressure from cement paste and hold its integrity until initial set of cement paste. Besides the condition of foam, water content in a mix will also affect the condition of foam in the mix. For lower water to cement ratio, cement paste will be too stiff causing foam to burst rapidly while at higher water to cement ratios, cement paste will be too thin to hold the foam causing segregation. (Nambiar and Ramamurthy, 2006). The consistency of cement paste is said to be perfect when the number is one. This means the fresh concrete's density is the same with desired density.

Stability of concrete is calculated by dividing fresh density of concrete to hardened density of concrete. By this means the most favorable result will be one as the fresh density is the same as hardened density. There are few factors that will affect the stability of concrete which include stability of foam, amount of water added, bleeding of cement paste and other factors which will cause a variation of density between fresh density and hardened density.

2.4.2 Hardened Properties

Compressive strength is the most important physical parameter of concrete. It explains the resistance to withstand direct axial load of the concrete. According to research by Ramamurthy, *et al*., (2009), it is found that the compressive strength of lightweight concrete decreases according to the reduction of density. Compressive strength is directly affected by the water to cement ratio, cement to aggregate ratio, surface texture, shape, strength and grading of aggregate as well as size of aggregate (Retrieved from: http://www.engineeringcivil.com/what-is-concrete-strength-and-what-are-the-factors-affecting-it.html).

Splitting tensile test is the indirect test that is carried out to determine the tensile resistance of concrete. A cylindrical specimen's accordance to ASTM standard is used as test specimen. According to research from N. Anoglu, *et al*. (2006), the ratio of splitting tensile strength to compressive strength is influenced by the concrete strength. For a low compressive strength, the ratio can be as high as 0.10 while at higher compressive strength, the ratio can be as low as 0.05.

Flexural strength test is used to determine the ability to resist bending or deformations of concrete. Concrete is usually assumed to possess 10% as strong of compression strength in tensile strength. (Anoglu, Girgin and Anoglu, 2006)

2.4.3 Poisson's Ratio

Poisson's ratio is the ratio of lateral strain to axial strain. It is produced when a uniaxial load is applied on the specimen. According to research from K.J. Byun, *et al*., (1998), the average Poisson's ratio obtained from lightweight foamed concrete is measured to be 0.2. This result is then confirmed by another researcher which the Poisson's ratio of lightweight concrete found is 0.22 (Harmon, 2005.).

2.5 Ordinary Portland Cement

Ordinary Portland cement is the most common type of cement used the market. It is used at any condition where no sulphates exposure occurs either in soil or groundwater. Ordinary Portland cement is classified as type 1 cement under standard reference ASTM C 150, BS12 and MS 522.

2.5.1 Chemical Composition of Portland Cement

Table 2.1 describes the general chemical composition of Portland cement. (Nevile, 2010)

Table 2.1: Chemical Composition of Ordinary Portland Cement. (Nevile, 2010)

Elements	Content,%
CaO	60.0 – 67.0
SiO_2	17.0 – 25.0
Al_2O_3	3.0 – 8.0
Fe_2O_3	0.5 – 6.0
Free Lime	2.0 – 3.5
MgO	0.5 – 4.0

2.5.2 Compound Composition of Portland Cement

Table 2.2 describes the compound composition that is present in ordinary Portland cement. (Nevile, 2010)

Table 2.2: Compound Composition of Ordinary Portland Cement. (Nevile,2010)

Component	Content, %
C_3S	42 – 67
C_2S	8 – 31
C_3A	5 – 14
C_4AF	6 - 12

2.6 Aggregate

Aggregate is commonly used as inert filler in ordinary concrete to fill the volume of concrete. Although aggregate is inert in nature, properties of aggregate will put effect on concrete. Generally, concrete is divided into two categories which is coarse aggregate and fine aggregate. Course aggregate is the aggregate which size is greater than 4.75mm while fine aggregate is aggregate which size smaller than 4.75mm. Fine aggregate is normally used in lightweight concrete.

Fineness modulus can be carried out to differentiate sizes of aggregate. A higher fineness modulus value shows a higher proportion of larger size aggregate vice versa. ASTM C33 suggests that fineness modulus of fine aggregate should be maintained between 2.3 to 3.1.

Finer aggregate will produce a larger total surface area. This will require more water in cement mix in order to maintain workability. Concrete with higher water content will result in lower compressive strength. (Kolias, *et al*., 2005).

2.7 Water to Cement Ratio

For typical normal weight concrete, the water to cement ratio that is used is in the range of 0.4 to 0.6. The lower the water to cement ratio the higher the strength will be. However, for the case of lightweight foamed concrete, not necessarily fulfill that statement. When less water is added to foamed concrete, less excess free water is available for hydration process which will cause cement paste to withdraw water from the foam. This will cause foam to burst and lost its initial purpose and density of the mix will thus increase. (Puttappa, *et al*., 2008). Hence, typical water to cement ratio will be used for foamed concrete ranging from 0.4 to 0.8.

2.8 Foam

The production of lightweight foamed concrete can be performed by either using pre-foaming method or after-foaming method. According to Byun, *et al*. (1998), pre-foaming method is described as foam are pre-formed before it is added into cement slurry during mixing procedure while after-foaming method is described as cement slurry is mixed with foaming agents during mixing procedure. Lightweight foamed concrete is produced by pre-foaming method. (Byun, *et al*., 1998). Pre-formed foam is formed by adding foaming agents with water into a foam generator with the ratio of 1 part of foaming agent to 30 parts of water. Foam generator will produce compressed air to blend all the material and finally pre-form foam is produced. The size of foam produced is in a range of 0.2mm to 0.8mm. The foam that is added must be capable of remaining stable and not easily collapse due to the pressure exerted by cement paste. (Byun, *et al*., 1998)

2.9 Eggshell

Eggshells are waste product generated by the world daily in a large amount of quantity. Eggshell wastes have been an issue in disposal problem because it will harbor fungal and bacterial growth which in turns may result in illness and allergies.

Through years, researchers from around the world had started to incorporate eggshell in their studies with the goal of reducing anthropogenic effects due to improper disposal of eggshells. Those researches includes eggshell as road work stabilizer, (Olarewaju, *et al*., 2011), eggshell as ceramic wall tile material, (Freire *et al*., 2006), Soil cement bricks incorporated with eggshell waste, (Mateus, *et al*., 2013), partial replacement of fine aggregate with eggshell in highway concrete structure, (Amusat, *et al*., 2007) and etc. The reason behind eggshell is being used as studied subject is because eggshells contain lime as well as calcium carbonate.

Previous study shows that by replacing 5% of eggshell into cement will increase the mechanical properties of normal weight concrete. (Yerramala, 2014). By referring to the research by Gowsika, *et al*., (2014), by incorporating eggshell as partial cement replacement had shown similar result as result done by Yerramala, (2014).

2.9.1 Chemical Composition of Eggshell

Eggshell is mainly made of 94% calcium carbonate, $CaCO_3$. The other 6% of eggshell are made up of phosphorus, magnesium, and trace amount of potassium, sodium, zinc, manganese, iron as well as copper. The percentage mentioned above is referred to percentage by weight. (Butcher and Miles, 2000)

2.9.2 Physical Properties of Eggshell

Table 2.3 describes the physical properties of eggshell found from the research by Hunton, (2005).

Table 2.3: Physical Properties of Eggshell (Hunton, 2005)

Name	Physical Properties
Specific Gravity	0.85
Moisture content	1.18
Bulk Density g/cm3	0.8
Particle Density g/cm3	1.012
Porosity (%)	22.4 BET
Surface area m2/g	21.2

Eggshell is a natural porous material as the shell enables air exchange between atmosphere and inner egg. This is to provide oxygen for hatchling. After grinding eggshells into powder, it is noticeable that eggshell powder contains a lot of micro-pores. Other than that, the shape of eggshell powder appears to be angular. Figure 2.1 shows the image by scanning electron microscope of eggshell powder.

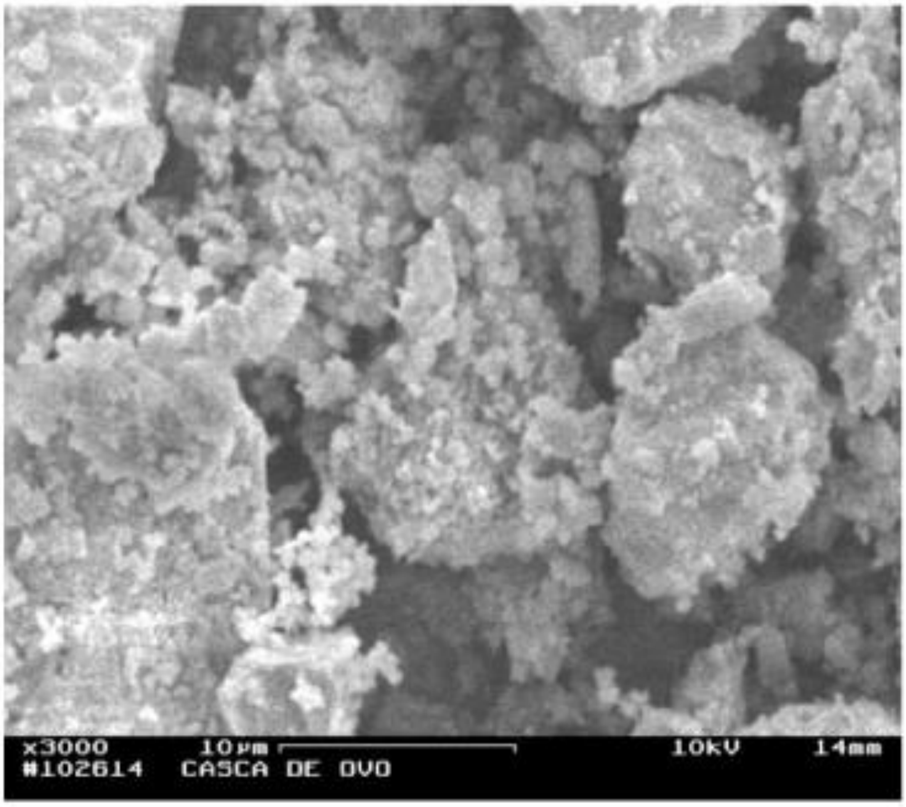

Figure 2.1: Morphological Details of Eggshell Powder (Freire, *et al*., 2006)

2.9.3 Advantages of Eggshell

There are many advantages of using egg shells in concrete. $CaCO_3$ which is the main compound in eggshell can increase the hydration of tri-calcium silicate which provides a higher early strength. Other than that, $CaCO_3$ acts as an active hydration participants as well as inert filler which both are beneficial towards hardened concrete. Another plus point is that egg shells have good durability and washable finish. It also resists growth of mould on the paint film. In the sense of cost saving, less material is required, thus, it saves the cost for the construction building as egg shells are practically wastes. In the architecture view, it also meets the aesthetic requirements and strict performance (egg shells are ground to become white powder; easier to absorb colour). (Sathanandhan *et al*., 2014).

Other than that, eggshell is a relative cheap material compared to other blended materials. This is because eggshell is considered worthless waste in food industry. Besides, eggshell can be easily collected in a large quantity from food industries source such as restaurant, pastry shop, egg processing plant, farms and so much more.

2.9.4 Limitation of Eggshell

The usage of eggshell in construction industry is still new and usage of eggshell may cause a lot of uncertainties. For example, eggshell is an organic material which means it is bio-degradable. Till now, there is not much information about period of degradation of eggshell when it is incorporated into concrete. Other than that, there is no information regarding the effects of degradation of eggshell on concrete

2.10 Calcium Carbonate

Calcium carbonate is the main chemical composition in eggshells. According to Matschei, *et al*., (2006), calcium carbonate serves two purposes when introduced in concrete. First will be active participants of cement hydration and the second is act as inert filler in concrete. Both can bring much benefit to concrete. Calcium carbonate as active hydration participants had been confirmed on studies from Medvešcek, *et al*., (2006). According to his research, Calcium carbonate can accelerate the hydration of tri-calcium silicate which will provide higher early strength. Other than that, it is noticeable that calcium carbonate had react completely with monosulfate that is present in concrete at 28 days and produces ettringite that fill up pores that presence in concrete which in turn reduces porosity. Other than that, back to research done by Matschei, *et al*., (2006), calcium carbonate will act as inert filler and will fill pores in concrete which in turns decrease the porosity and permeability of concrete hence will increase strength.

2.11 Summary

Lightweight foamed concrete is formed by combining cement, fine aggregate, water and foam. Foam is essentially crucial because it determines the density of the concrete. Foam can be formed by either pre-form foaming method or after-form forming method. The advantages of lightweight foamed concrete include lower density, excellent thermal and sound insulator and high workability provides ease of transportation, casting and placing.

Eggshell powders which is rich in calcium carbonate which play an important role in hydration process. It can replace certain ratio of cement in the blended Portland cement to reduce the cement content involved in concrete mixing. Eggshell is a food industry by-product waste that are produced in massive quantity daily and its potential to replace the cement content has not yet fully released for past centuries. This case study reviews and discusses the performance of eggshell mixing in lightweight foamed concrete.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discusses about the methodology of this study. The scope of methodology covers from raw material used, mixing procedure to the test methods used in this study.

3.2 Raw Material

In this section, all the materials used namely ordinary Portland cement, eggshell, fine aggregate, foaming agent and water in order to produce lightweight foamed concrete.

3.2.1 Ordinary Portland Cement (OPC)

Ordinary Portland cement used in this study is ORANG KUAT branded OPC which is a product from one of the largest cement manufacturers in Malaysia, YTL Cement Sdn. Bhd. The physical properties of ORANG KUAT OPC is specific gravity of 3.15 (density = 3150 kg/m^3) and fineness = 3170cm^2/g. Other than this properties, ORANG KUAT OPC also in compliance with the Malaysian Standard of MS 522: Part 1: 2003 and it is certified by MS ISO 14001 and OHSAS 18001. To make sure there is no hydrated clinker in the cement, the OPC have to first 100% sieve through 300µm sieve. The sieved OPC is then being kept under an air-tight container which prevents premature hydration process caused by humid air. The chemical composition of ORANG KUAT OPC is shown at Table 3.1. Figure 3.1 shows the OPC that is used in this study.

Table 3.1: Percentage of Chemical Composition of ORANG KUAT branded OPC by Weight. (Ali, Khan and Hossain, 2008)

Material	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	Free lime
OPC	65.0	21.0	6.00	3.50	0.70	1.50	2.00

Figure 3.1: ORANG KUAT Branded OPC

3.2.2 Fine Aggregate

Sand used in this study is localized quartz type river sand.First, the sand was oven dried under temperature in the range of 105°C to 115°C for at least 24 hours to remove all the moisture that contained in the sand particles. Oven dried sand provide ease of sieving compared to wet sand.

In order to meet the compliance of ASTM C778 (1991), the fine aggregate used was 100% sieve through 600μm sieve. Figure 3.6 shows the fine aggregate used in this study.

Figure 3.2: Fine Aggregate

3.2.3 Eggshell

Localize eggshells were collected and had been wash with intense care due to eggshell is a very fragile material. The entire egg residue was washed out followed by the removal of protein membrane within the eggshell. After that, those eggshells were allowed to be dried under the sun to remove all the moisture. Oven dry is not an option of drying the material due to eggshell is organic material. In order to prevent accident such as burning of the material inside the oven, natural way of drying was chosen.

After the drying process, those eggshells were crushed to small pieces before the eggshells were being blended into powder. After the eggshells were blended into powder, the eggshell powders were sieved through 63µm sieve. The aim of the sieving is to ensure eggshell particles have size similar with to cement. Sieved eggshell powders were kept in air-tight container to prevent contact of moisture. Figures 3.3 to 3.6 show the transformation of eggshells into eggshell powder.

Figure 3.3: Eggshells Undergo Drying Process

Figure 3.4: Crushed Eggshells

Figure 3.5: Blender

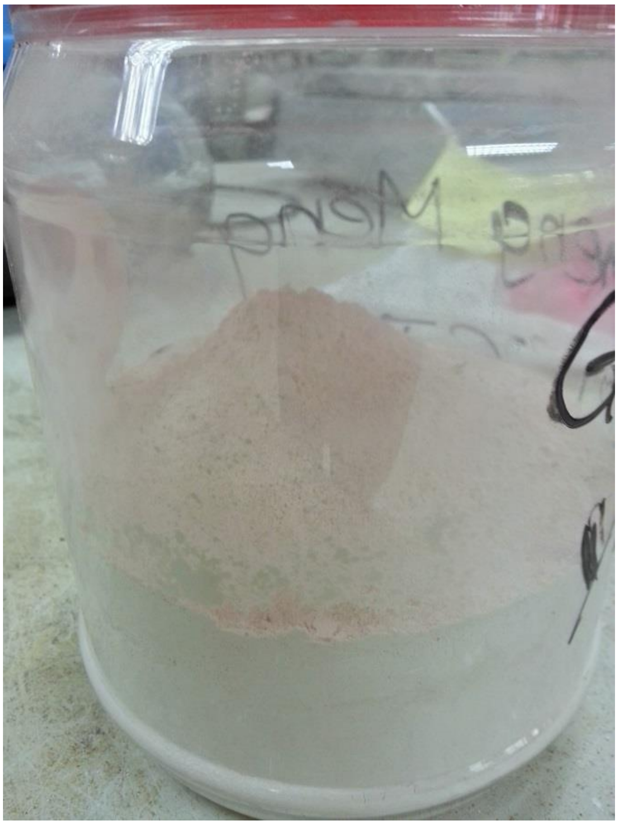

Figure 3.6: Eggshell powder stored in air-tight container

3.2.4 Foam

Foam controls the density of lightweight foamed concrete. There are two methods in producing foam which are pre-form foaming method and after-form foaming method.

In this study, a pre-form foaming method was used. Pre-form foaming method requires a foaming generator. First, foaming agent was mixed with water with the ratio of 1 part of foaming agent to 30 parts of water. The solution was introduced to the foaming generator. The foaming generator was sealed and compressed air was then introduced. The compressed air created a pressure of 0.5MPa inside the foaming generator and foam was produced. Eventually the density of produced foam was in the range of 40 to 50 kg/m^3.

It is necessary to ensure that the foam must stay firm and stable when it is introduced to the cement paste so that the foam can withstand the pressure exerted by cement paste, mixing process and placing of cement in order to prevent burst of foam. Figure 3.7 and 3.8 show the produced foam and foam generator respectively.

Figure 3.7: Foam

Figure 3.8: Foam Generator

3.2.5 Water

Water used is from municipal water supply tap. In accordance to ASTM C1602 (2006), this type of water is allowed to be used as mixing water. Water is one of the most important constituents to produce lightweight foamed concrete. For concrete curing, water is used. Besides, water was used for mixing and incorporated in the concrete during production. The water used should not contain any substances from foreign and harmful materials because the impurities may affect the process of hydration of cement and durability of concrete.

3.3 Mould

In this study, three types of mould were used to cast different types of concrete specimens. By referring to the standards from ASTM as well as BS codes, cubic cubes with dimension of 100 mm x 100 mm x 100 mm were used to carry out compressive test, cylindrical specimens with the dimension of 100 mm radius x 200 mm height was used to carry out splitting tensile test and Poisson ratio study, prismatic mould with the dimension of 25 mm x 25 mm x 250 mm was used to carry out flexural strength test. Before fresh cement paste was placed into the mould, the mould had to be cleaned with no residue in it. Then, all the bolts that hold the mould together must be tighten to avoid mould failure and lastly a layer of oil was coated to the mould to provide ease of de-moulding.

3.4 Trial Mix

Trial mix is a necessary procedure to be done before any test can be carried out. This is mainly because the study of effect of eggshell on concrete is very limited, hence the optimal water to cement ratio is practically unknown. To obtain the optimal water to cement ratio of lightweight foamed concrete incorporated with 10% of eggshell as cement replacement. The lightweight foamed concrete was cast at different water to cement ratios and the strength results obtained were used to screen the trial mixes for optimal w/c ratio. Four different water to cement ratios were used which ranging from 0.52 to 0.64 with each interval of 0.04 for the screening purpose.

3.5 Mixing Procedure

The mixing of LFC-CTR and LFC-ES10% was similar to each other. The only difference between them was the material used. LFC-ES10% had incorporated 10% of eggshell as cement replacement to the mix.

First and for all, a design mix was produced in order to obtained the desired density of 1300kg/m^3. It was very difficult to obtain the exact desired density for every mix. Hence, a tolerance of 50kg/m^3 was added to the desired density which means the desired density was in a range of 1250kg/m^3 to 1350kg/m^3.

Secondly, all materials were being weighted according to the design mix proportion before mixing stage. Then, the dry materials were being added into the mixing bowl according to their particle size, from smaller particle size towards larger particle size. Figure 3.9 shows the mixing of dry materials. After all the dry materials were mixed evenly, the mixture was continuously mix while water was added in gradually. Meanwhile, foam was being produced by foamed generator. After the cement mix was thoroughly mixed, initial fresh density was measured followed by flow table test. After flow table test, foam generated was introduced into the mix and the mix continuously mixed until uniform mixture obtained. 2nd density measure was carried out followed by inverted slump test. After the inverted slump test was done, 3rd fresh density was measured. Foam to be added in this phase if the density of LFC did not fall in the range.

After the desired density had been achieved, the mixture was then cast as shown at Figure 3.10. The fresh concrete was left for 24 hours for setting and hardening. After 24 hours, the hardened concrete was de-moulded and its hardened density was measured. Lastly, the concrete cube was incubated into a water tank for hydration process.

Figure 3.9: Mixing of Dry Materials

Figure 3.10: Casting of Concrete

3.6 Fresh Concrete Test

There are a few tests that had been carried out in this study in order to obtain the fresh properties of concrete. The tests include fresh density test, flow table spread test and inverted slump test.

3.6.1 Fresh Density Test

Fresh density test was carried out in accordance with ASTM C796 (2012). A container with 1 liter volume was produced. The weight of the container was measured and recorded. Then, the container was overfilled with concrete with slight gentle taping at the side of the container to prevent the presence of air void. The overflow concrete was then trimmed off and the surface was ensured flat. The container with fresh concrete in it was then being weighted and the weight was recorded. The fresh density of concrete can be accurately obtained by deducting the weight of container and fresh concrete with that of empty container. This step was repeated at least twice to maintain the consistency of result. Figure 3.11 shows the container with concrete is being weighted.

Figure 3.11: Container with Concrete is being Weighted on Weighing Machine

3.6.2 Flow Table Test

The purpose of this test is to determine the consistency and the flow-ability of the cement mortar corresponding to the water to cement ratio used. This test was carried out before foam was introduced to the cement mortar mixture. The test was carried out in accordance with ASTM C230 (2003). Figures 3.12 and 3.13 show filling of cement into cone mould and spreading of fresh cement mortar respectively.

Figure 3.12: Filling Cement Mortar into Cone Mould

Figure 3.13: Spreading of Fresh Cement Mortar

3.6.3 Inverted Slump Cone Test

According to ASTM C 1611 (2005), it is mentioned that there are two option for filling cone mould. It is either filled with upright mould or inverted mould. For this study, slump cone was placed in a pan inversely followed by filling up fresh lightweight foamed concrete until slightly overfill but yet to overflow. It is crucial that the cone must be firmly pressed on the ground with no leaking observed while the cement mixture was filled into the inversed cone. The mould was lifted up vertically to 1ft of height. The four different angles of diameter of spread was measured and recorded. Inverted slump test was used in the test due to the high flowability of lightweight foamed concrete. If halo is present during the test, a second diameter will be needed to be measured as mentioned in ASTM C1611 (2005). Figures 3.14 and 3.15 show lifting of slump cone vertically and spreading diameter is being measured respectively.

Figure 3.14: Slump Cone was Lifted Vertically

Figure 3.15: Slump Diameter is Being Measured

3.7 Curing Condition

In this study, water curing method was used as shown in Figure 3.16. The objective of water curing is to ensure full hydration of concrete. Concrete samples were all incubated in a water tank after they were de-moulded. The curing period adopted were 7, 28, 56, 90, 180 days. The temperature of curing water was in a range of 25°C to 30°C.

Figure 3.16: Water Curing

3.8 Destructive Test of Hardened Concrete

In this study, all test conducted are destructive test. INSTRON 5582 model was used to perform tests. Before any destructive test was carried out, specimens prior for testing were taken out from water tank and were dried in oven to remove all the moisture in the concrete.

3.8.1 Compressive Strength Test

Compression test was carried out by referring to the standard from BS EN 12390-3 (2002). INTRON 5582 was used as a platform for compression test. Cubic specimens with dimension of 100 mm x 100 mm x 100 mm were adopted in compression test as shown in Figure 3.17. The axial compression load rate was pre-set to 0.02 mm/s. A slow rate was introduced to the specimen to avoid any sudden failure of specimen which will cause inaccurate result. Dimension of each specimen was measured before commencement of compression test. The compression test for LFCs were done in triplicate, but only the average values were reported in this study. Compressive strength can be calculated by using Equation 3.1.

$$f = P/A \tag{3.1}$$

Where:

f = Compression strength of cube, MPa
P = Maximum load applied, N
A = Area, m^2

Figure 3.17: Compressive Strength Test

3.8.2 Splitting Tensile Test

Splitting tensile test was performed by referring to ASTM C496 (2004). Strips of plywood were placed between top and bottom of the specimens to allow uniform distribution of applied load as shown in Figure 3.18.

Loading rate of INSTON 5582 was pre-set at 1.2mm/min. Cylindrical specimens with radius of 100 mm and 200 mm of height were used in this test. The specimen was loaded until the specimen was completely failed. The splitting tensile test for LFCs were done in triplicate, but only the average values were reported in this study. The maximum load obtained was used to calculate splitting tensile strength by applying the Equation 3.2.

$$T = \frac{2P}{\pi l d} \qquad (3.2)$$

Where:

T = Splitting tensile strength, MPa

P = maximum applied load, N

l = Length of specimen, mm

d = Diameter, mm

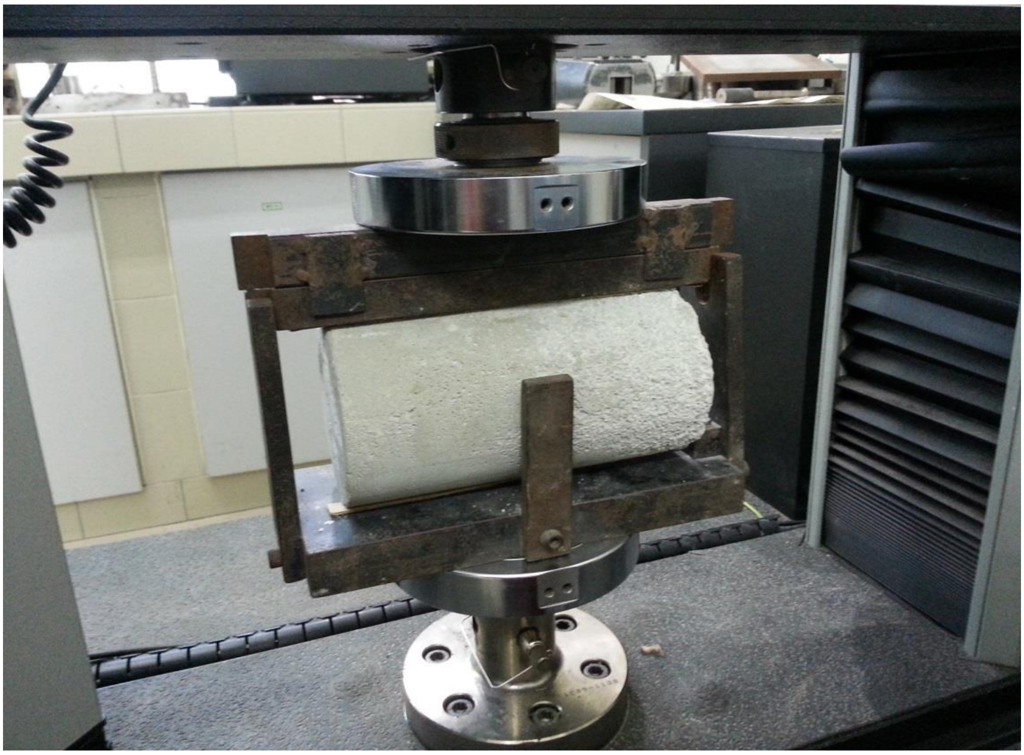

Figure 3.18: Splitting Tensile Test of Lightweight Foamed Concrete

3.8.3 Flexural Strength Test

Flexural strength test was performed with center point loading method in accordance with ASTM C293 (2002). Prismatic specimens with the dimension of 25 mm x 25 mm x 250 mm were used in this test as shown in Figure 3.19.

A 10mm offset from the end of both sides of prism was marked and the prism was placed on the support block. The specimen was loaded gradually with constant rate of loading until failure. The flexural strength test for LFCs were done in triplicate, but only average values were reported in this study. The flexural strength can be calculated by applying Equation 3.3.

$$R = \frac{3Pl}{2bh^2} \tag{3.3}$$

Where:

R = flexural strength, MPa

P = maximum load applied, N

l = length of specimen, mm

b = width of specimen, mm

h = depth of specimen, mm

Figure 3.19: Flexural Strength Test of Lightweight Foamed Concrete

3.8.4 Poisson's Ratio

By referring to ASTM C469 (2002), cylindrical specimen with dimension of 100 mm diameter and 200 mm height was used for the test as shown in Figure 3.20. The Poisson's ratio can be calculated by applying Equation 3.4.

$$\mu = \frac{et2 - et1}{e2 - 0.00005} \tag{3.4}$$

Where,

μ= Poisson's ratio

e_{t2} = lateral strain at 0.4 f'_c

e_2 = longitudinal strain at 0.4 f'_c

e_{t1}= lateral strain at S_1

$f'_{c=}$ Compressive strength, MPa

By applying Equation 3.5, modulus of elasticity, E can be obtained.

$$E = \frac{S2-S1}{\epsilon 2 - 0.000050} \tag{3.5}$$

Where,

E = Chord modulus of elasticity, psi,

S_2 = Stress corresponding to 40% of ultimate load,

S_1 = Stress corresponding to a longitudinal strain, ϵ_1 , 50 millionths, psi, and

$\epsilon 2$ = Longitudinal strain produced by stress S2.

Figure 3.20: Poisson's Ratio Test Set-up

3.8.5 Compressive Toughness

Compressive toughness was determined based on compressive stress-strain relationship graph plotted. Area under stress-strain diagrams represented total energy to fracture each sample. It is computed by using integration method as shown in Equation 3.6

$$\mu_t = \int_0^{\varepsilon_f} \sigma \, d\epsilon \qquad (3.6)$$

Where,

μ_t = 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

Consistency and stability can be calculated by the fresh density and hardened density that were obtained from each specimen. Theoretically, consistency and stability of concrete is favored to be one. Consistency and Stability can be determined by applying Equations 3.9 (Ramamurthy, *et al.*, 2009) and Equation 3.10 (Lim *et al.*, 2013)

$$Consistency = \frac{Fresh\ Density}{Desired\ Density} \tag{3.9}$$

$$Stability = \frac{Fresh\ Density}{Hardened\ Density} \tag{3.10}$$

3.10 Performance Index

Performance Index (PI) is a parameter used to determine the compressive strength per 1000kg/m^3 density. Samples with variation of density show difficulty in comparison of compressive strength. Hence, performance index is introduced. Performance index can be calculated by applying Equation 3.11.

$$\mathrm{PI} = \frac{f}{\text{hardened density}/_{1000}} \tag{3.11}$$

Where:

PI = Performance Index, MPa per 1000kg/m^3

f = Compressive Strength, MPa

3.11 Summary

LFC-CTR and LFC-ES10% were produced by pre-foaming method. Stable and dry foam was introduced into fresh lightweight foamed concrete until desired density achieved. Two mix proportions were prepared in this study namely LFC-CTR and LFC-ES10%. Mould of 100 mm cubes, cylindrical mould with 100 mm diameter and 200 mm height and prismatic mould with 25 mm x 25 mm x 250 mm were used in this study. All specimens were cure in water for 7, 28, 56, 90 and 180 days prior for testing namely compressive strength test, splitting tensile test, flexural test, Poisson’s ratio, compressive toughness, porosity and water absorption.

CHAPTER 4

SCREENING OF TRIAL MIXES

4.1 Introduction

This chapter shows the data obtained from trial mixes of lightweight foamed concrete incorporated with 10% eggshell as cement replacement material. The purpose of trial mixes is to find an optimum water cement ratio for the mix proportion for LFC-CTR and LFC-ES10. Each of the concrete samples was water cured for 7 and 28 days before tested with compression test.

4.2 Trial Mix for LFC-CTR

First and foremost, four water/cement ratios were used for the casting of control lightweight foamed concrete (LFC-CTR) which is 0.52, 0.56, 0.60, and 0.64. The purpose of trial mixes is to obtain an optimal w/c ratio for LFC-CTR. Table 4.1 shows the mix proportion for LFC-CTR based on 1300±50kg/m^3 volume.

Table 4.1: Mix Proportion for LFC-CTR based on 1300±50kg/m³ Volume

Specimen	w/c ratio	Materials (kg/m³)			
		Cement	Sand	Water	Foamed
LFC-CTR-0.52	0.52	500	500	260	16.6
LFC-CTR-0.56	0.56	500	500	280	17.9
LFC-CTR-0.60	0.60	500	500	300	17.3
LFC-CTR-0.64	0.64	500	500	320	17.3

4.2.1 Fresh Properties

Table 4.2 shows the fresh properties of control LFC. The desired density for consistency calculation is 1300kg/m³.

Table 4.2: Fresh Properties of Trial Mix for LFC-CTR

Specimen	Fresh Density (kg/m³)	Hardened Density (kg/m³)	Flow table Spread, No. of drops	Average Inverted Slump Diameter (mm)	Stability	Consistency
LFC-CTR 0.52	1330.0	1406.4	>250, (24 drops)	498.75	0.9457	1.0231
LFC-CTR 0.56	1349.0	1465.1	>250, (21 drops)	602.5	0.9207	1.0377
LFC-CTR 0.60	1360	1341	>250, (13 drops)	764.0	1.0140	1.0462
LFC-CTR 0.64	1307	1322	>250,(8.5 drops)	845.0	0.9883	1.0054

Based on Table 4.2, it is noticed that fresh densities of LFCs can be maintained at a desired range of density except LFC-CTR-0.60. This might be caused by the quality of foam added to the mix. With a low quality of foam produced, it is difficult to maintain the integrity of foam. During mixing procedure, low quality foams are more likely to burst resulting in a higher density mix.

For the flow table spread number, the number of blows decreases as the increase of water to cement ratio. This shows an improved in workability as the fresh concrete requires less blows to spread across 250mm of flow table. The increase of water to cement ratio leads to increasing of the diameter of inverted slump spreading. This again had proven that the workability of cement mixture increase with the increase of water to cement ratio.

From Table 4.2, it is noticeable that the stability and consistency of concrete are nearly to unity corresponding to the increment of water to cement ratio. This shows that the condition of air bubbles were well maintained.

4.2.2 Compressive Strength

Figure 4.1 shows the compressive strength results of LFC-CTR with four different water to cement ratios at 7 days and 28 days of curing ages.

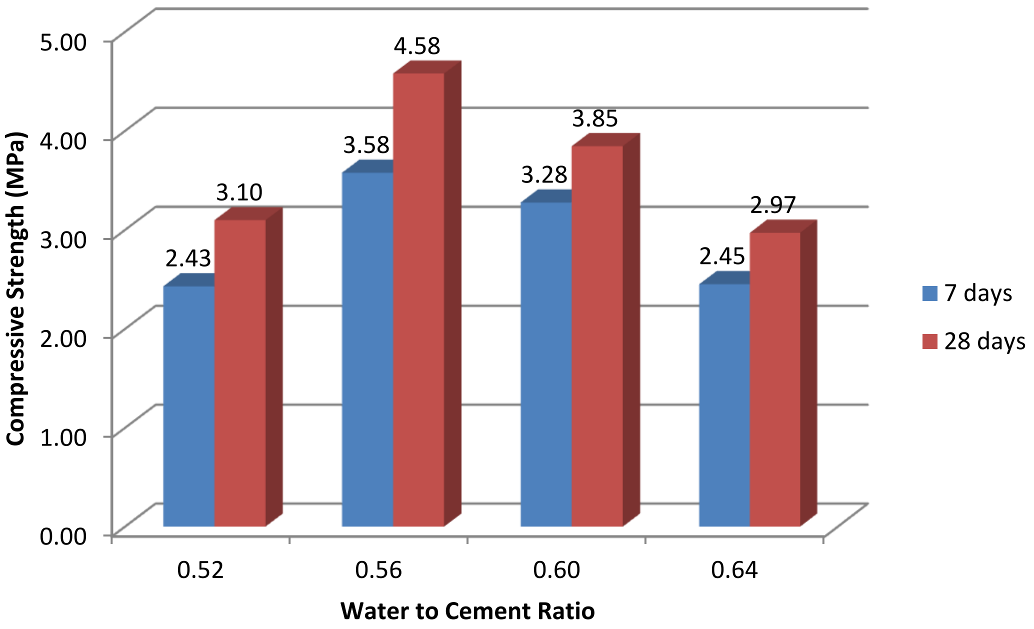

Figure 4.1: 7 and 28 Days Compressive Strength of LFC-CTR at Four Different Water to Cement Ratios.

From the result shown in Figure 4.1, LFC-CTR-0.56 obtained the highest compressive strength. For higher water to cement ratio, mixes such as LFC-CTR-0.60 and LFC-CTR-0.64, their compressive strength are low due to the lower cement content in the mixture. Less cement content reduced the formation of C-S-H gel, thus weakens the bonding between particles and produced weaker concrete specimens. For low water to cement ratio such as LFC-CTR-0.52, the insufficient free water content for hydration process had led to low compressive strength..

4.2.3 Performance Index

Performance index is a method used to determine concrete's strength performance based on the density of the concrete cube. In this study, a desired density of 1300kg/^{m3} had to be maintained. However, it is very difficult to maintain the desired density for each of the samples. Hence, performance index is needed for comparison purpose. In this case, a higher value of performance index is preferable. Figure 4.2 shows the performance index for 7 days and 28 days results.

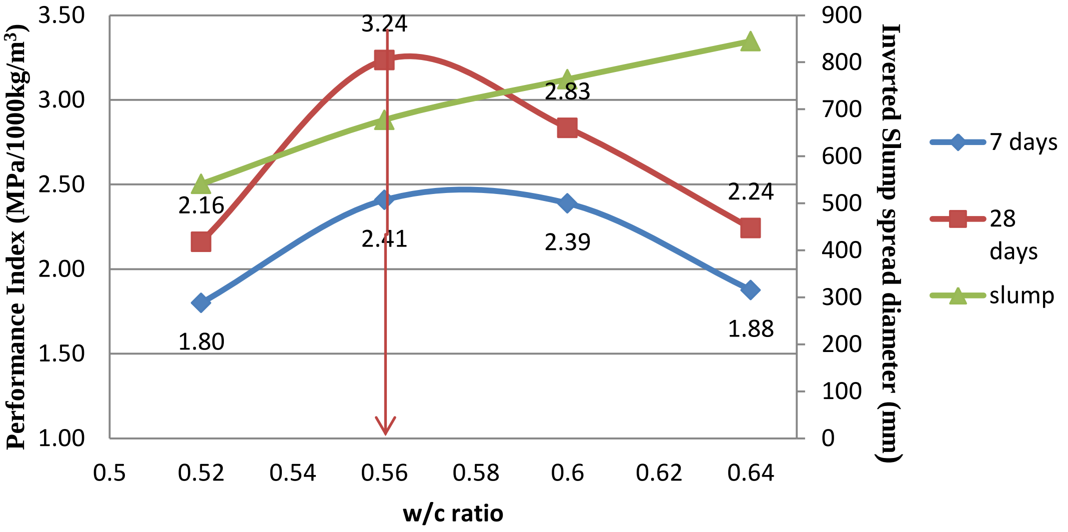

Figure 4.2 : Relationship among Performance Index, Inverted Slump Value and Water to Cement Ratio for LFC-CTR

Based on Figure 4.2, optimal water cement ratio can be obtained by selecting the corresponding highest performance index. In this case, the optimum water to cement ratio for LFC-CTR is 0.56.

4.3 Trial Mix for LFC-ES10%

The purpose for casting trial mix for LFC-ES10 is to obtain the optimal water/cement ratio for LFC with eggshell as cement replacement material. The optimal mix obtained in these trial mixes was compared with optimal LFC-CTR for further study of their engineering properties. Table 4.3 shows the mix proportion for the trial mix of LFC-ES10.

Table 4.3: Mix Proportion for Trial Mix of LFC-ES10% based on density of 1300kg/m³

Specimen	w/c ratio	Materials (kg/m³)				
		Cementitious		Non-cementitious		
		Cement	Eggshell	Sand	Water	Foamed
LFC-ES10%-0.52	0.52	450	50	500	260	20
LFC-ES10%-0.56	0.56	450	50	500	280	20
LFC-ES10%-0.60	0.60	450	50	500	300	19.2
LFC-ES10%-0.64	0.64	450	50	500	320	16

4.3.1 Fresh Properties

The fresh properties of concrete with eggshell as part of cement replacement were recorded during the casting process. Those data were tabulated in Table 4.4.

Table 4.4: The Fresh Properties of LFC-ES10 at Four Different Water Cement Ratios

Specimen	Fresh Density (kg/m³)	Hardened Density (kg/m³)	Flow table Spread, No. of drops	Average Inverted Slump Diameter (mm)	Stability	Consistency
LFC-ES10 0.52	1328	1371	>250, (20.5 drops)	517.5	0.9685	1.0215
LFC-ES10 0.56	1310	1314	>250, (13 drops)	596.0	0.9968	1.0077
LFC-ES10 0.60	1310	1327	>250, (7 drops)	710.0	0.9871	1.0077
LFC-ES10 0.64	1328	1340	>250,(5 drops)	724.5	0.9911	1.0215

From Table 4.4, it is noticed that the trend of data is similar with LFC-CTR. Densities for 3 different specimens were controlled at 1300kg/m^3 $\pm$ 50kg/m^3. The number of drops for flow table spread decreased with the increment of water to cement ratio while the average diameter of inverted slump value increased with the increment of water to cement ratio. This is due to the excess free water in the cement paste resulting a high fluidity and workability mix.

The consistency and stability of all LFC-ES10% are near to unity. The stability and consistency values represented that the condition of air bubbles in the mix were firm and the mixtures were uniform.

4.3.2 Compressive Strength

Figure 4.3 tabulates the compressive strength of trial mix of LFS-ES10 based on 7 and 28 days of curing periods.

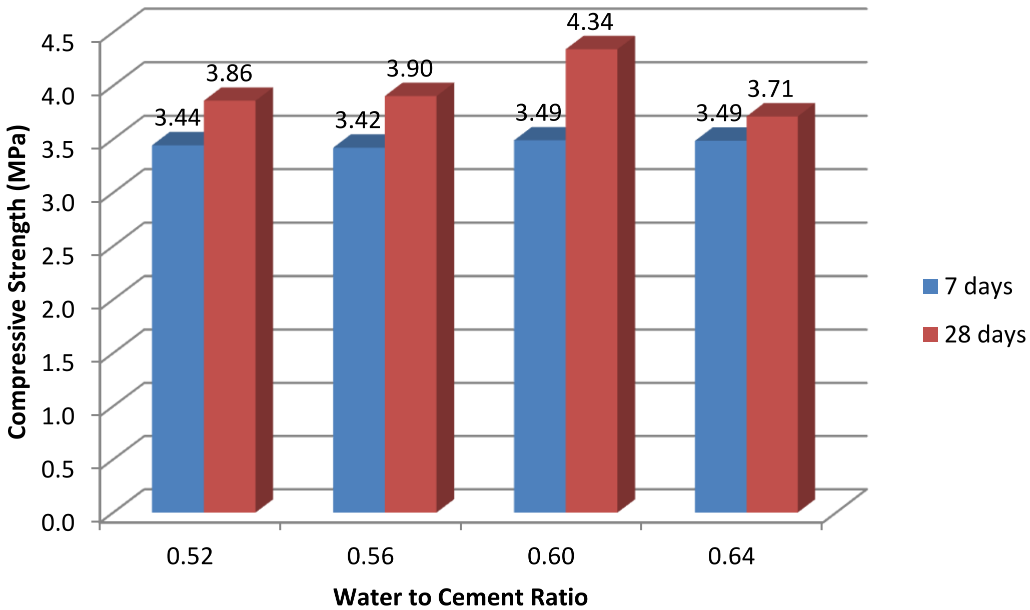

Figure 4.3: 7 days and 28 days compressive strength of LFC-ES10 at various water to cement ratios.

From Figure 4.3, it is clearly stated that the highest compressive strength obtained by various water to cement ratios is at LFC-ES-0.60. This result is different from control mix as the highest compressive strength of control mix was achieved at water to cement ratio of 0.56. This phenomenon occurred due to eggshells used contained a lot of microscopic pores compared to cement grain which in turn absorbed more water to completely wet the surface of eggshell grains. In this case, more free water had been absorbed by eggshell powder causing an increase of water to cement ratio to achieve optimal condition.

4.3.3 Performance Index

Figure 4.4 shows the performance index for LFC-ES10 based on the relationship between compressive strength and density of 7 and 28 days for four different water to cement ratios.

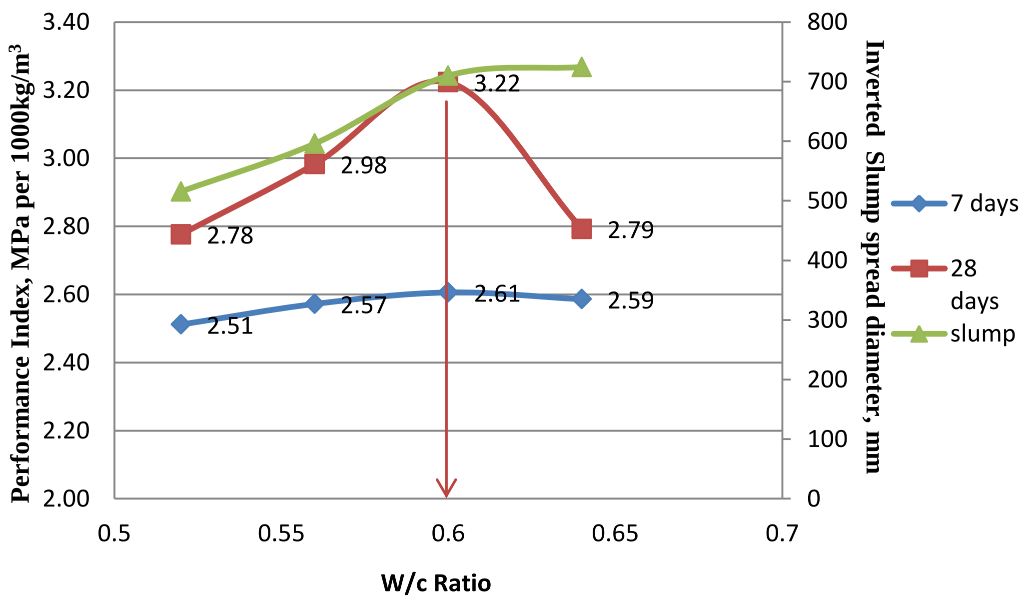

Figure 4.4: Relationship among performance index, inverted slump value and water to cement ratio for LFC-ES10

From Figure 4.4, it shows that the optimal water to cement ratio of LFC-ES10 is 0.60 as it possesses the highest performance index of 7 and 28 days compared to the other water to cement ratios. This phenomenon is due to the water absorption of eggshell.

4.4 Comparison of Workability

As mentioned in the literature review, eggshell is a porous material which means eggshells contains small pore that tends to absorb water during mixing process. According to P.C Hewlett, (2006), 18% of commercial ordinary Portland cement particle size is larger than 60 µm. On the other hand, eggshell powder used for replacement is 100% passing 63µm sieve. Although cement grains are generally finer than eggshell powder, due the porous structure of eggshell powder, it requires more water to wet hence produces a more viscous mix.

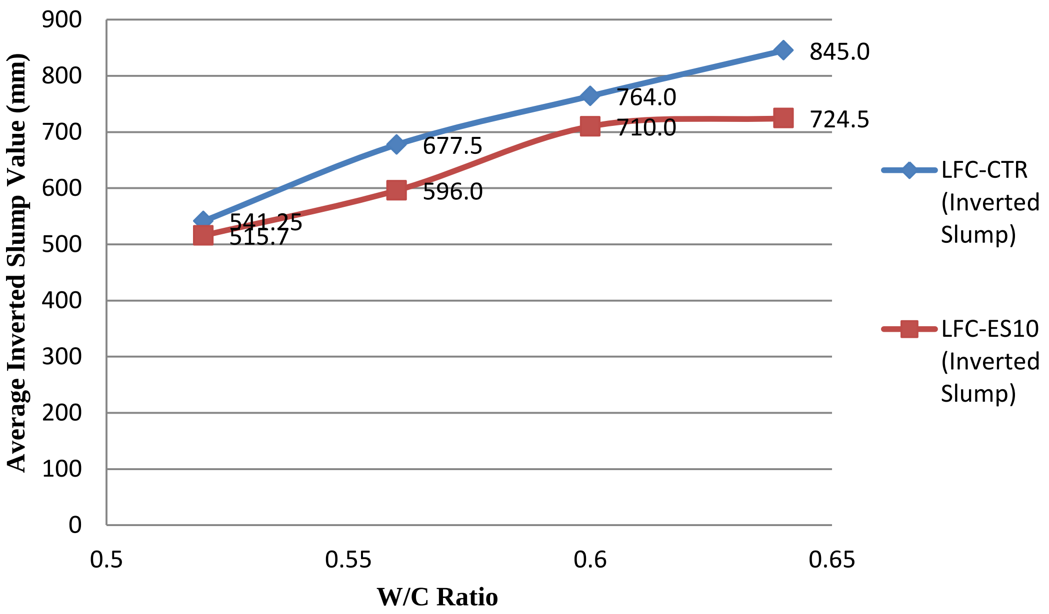

Figure 4.5: Relationship between average inverted slump value and water to cement ratio

Figure 4.5 shows that LFC-ES10 tends to behave stiffer than that of control lightweight foamed concrete. This can be proven by comparing the average inverted slump diameter of LFC-CTR to LFC-ES10. Result obtained by trial mix clearly proven that LFC-ES absorbed more water compared to LFC-CTR due to the porous structure of eggshell incorporated in the LFC-ES10%.

4.5 Comparison of Foamed Volume

From Figure 4.6, it is noticed that generally the amount of foam to achieved desired density in LFC-ES10% is larger.

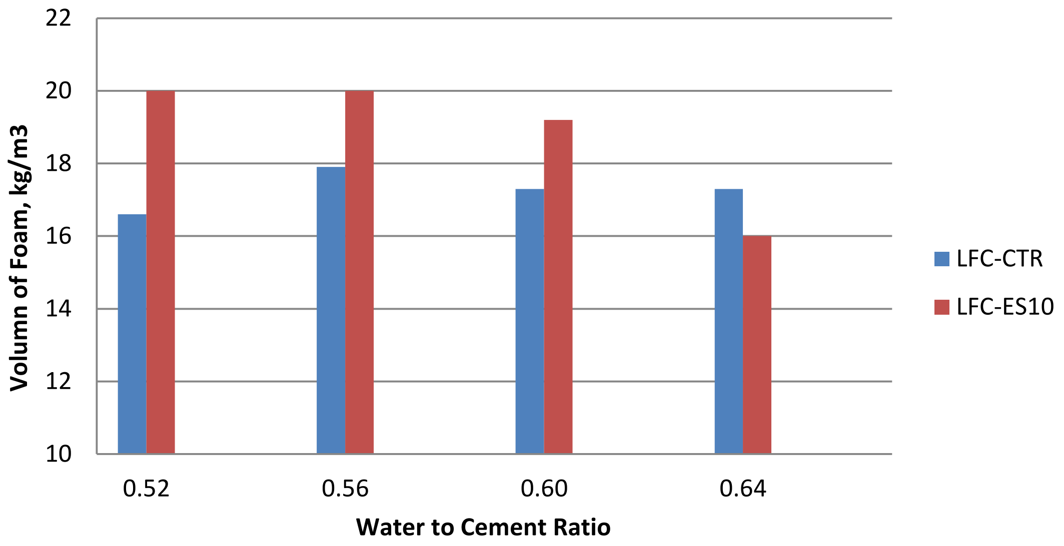

Figure 4.6: Comparison of Foamed Added Between LFC-CTR and LFC-ES10%

4.6 Summary

From the results discussed in this chapter, the optimal water to cement ratio for LFC-CTR was determined as 0.56 while the optimal water to cement ratio of LFC-ES10% was determined to be 0.60. It is also shows a significant of decrease of workability of LFC-ES10% compared to that of LFC-CTR.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Introduction

This chapter discusses about results of tests that had been carried out on lightweight foamed concrete incorporated with eggshell as 10% partial cement replacement namely compressive strength test, splitting tensile test, flexural test, Poisson's ratio test, porosity and water absorption test. All the samples except cylinder for Poisson's ratio are categorized into five different water curing periods of 7, 28, 56, 90 and 180 days prior to testing. Samples for Poisson's ratio are left for curing for 28, 90 and 180 days of ages. Effects of incorporation of 10% eggshell powders as partial cement replacement of lightweight foamed concrete on its engineering properties in terms of compressive, splitting tensile and flexural strength as well as Poisson's ratio and compressive toughness had been investigated.

5.2 Compressive Strength Test

Compressive strength test results for LFC-ES10% and LFC-CTR are presented in Figure 5.1.

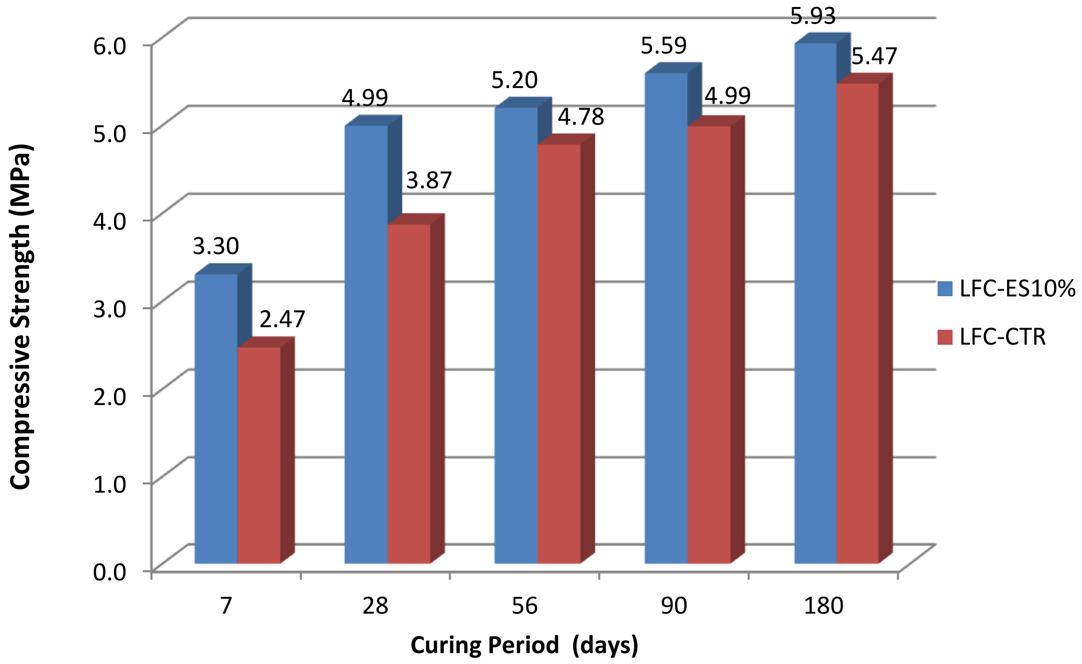

Figure 5.1: Compressive Strength Development up to 180 days of age for LFC-ES10% and LFC-CTR.

From Figure 5.1, the trend of strength development is clear which shows an increase of strength throughout the curing periods for both LFC-ES10% and LFC-CTR. By comparison, LFC-ES10% has a higher early strength compared to that of LFC-CTR. As curing period increases, both compressive strengths of LFC-ES10% and LFC-CTR increases but incremental of later strength for LFC-CTR was much more drastic compared to that of LFC-ES10%. At age of 180 days, LFC-ES10% recorded a higher compressive strength compared to that of LFC-CTR.

As mentioned in literature review, 94% of eggshell powder is made of calcium carbonate. According to Matschei, *et al*., (2006), one of the purposes of calcium carbonate is to accelerate the hydration of tri-calcium silicate which is the essential compound that responsible for early strength of concrete. By looking at results presented in Figure 5.1, LFC-ES10% specimens 7 and 28 days strengths are significantly higher than that of LFC-CTR specimens. By looking at the later strength of LFC-ES10%, its incremental rate of strength decreased compared to that of LFC-CTR. This might due to most of the calcium in the concrete had been activated and reacted with C_3S at early age. LFC-ES10% has a higher later strength compared to that of LFC-CTR. This can be explained as calcium carbonate can be acted as inert filler. (Matschei, *et al.*, 2006). The inert filler filled up the micropores in LFC thus denser the concrete matrix and subsequently increased the compressive strength of the LFC. Table 5.1 illustrates the effect of eggshell on strength development of lightweight foamed concrete at 180 days of curing period.

Table 5.1: Effect of Incorporation of Eggshell in LFC in terms of Compressive Strength at 180 Days of Curing Period.

Age	Mix	Strength development of LFC-ES10% compared to that of control mix at 180days of age
180 days	LFC-CTR	100%
	LFC-ES10%	108%

5.3 Splitting Tensile Strength Test

Splitting tensile strengths of LFC-ES10% and LFC-CTR are presented in Figure 5.2

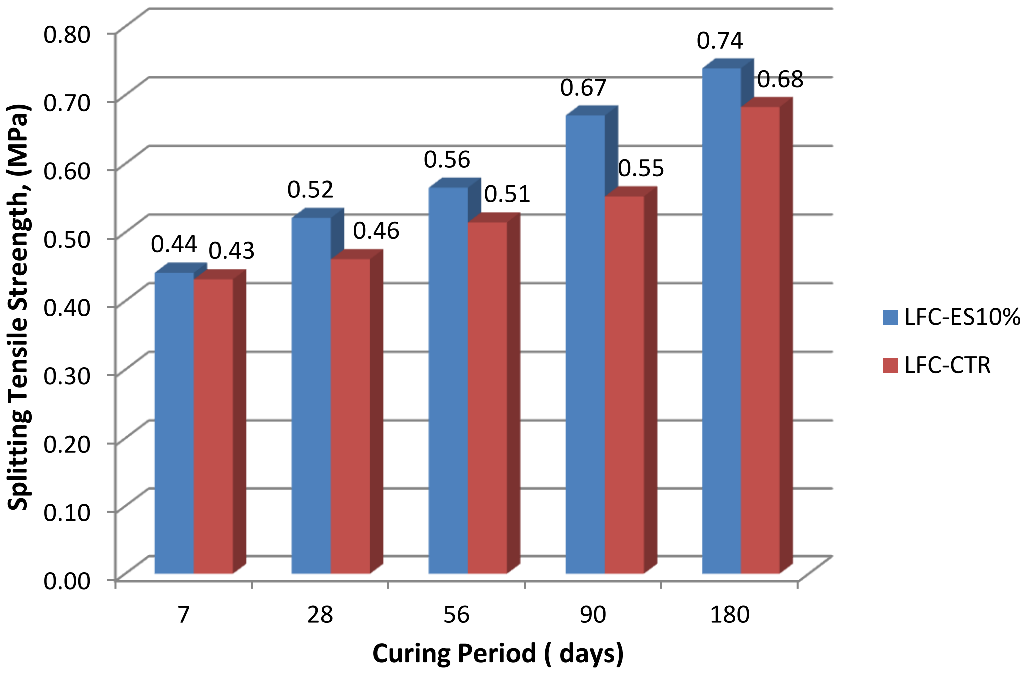

Figure 5.2: Splitting Tensile Strength Development up to 180 days of age for LFC-ES10% and LFC-CTR.

Figure 5.2 presents the splitting tensile stress of LFC-ES10% and LFC-CTR of each of the curing period ranging from 7 days till 180 days. Data presented from Figure 5.2 show a trend of increased in splitting tensile stress throughout the curing periods for both LFC-ES10% and LFC-CTR. LFC-ES10% obtained a higher splitting tensile strength at 180 days of curing period compared to that of LFC-CTR.

LFC-ES10% generally possessed higher splitting tensile strength compared to that of LFC. Parra (2011) stated that, splitting tensile strength of concrete is highly dependent to compressive strength but this relationship also depends on other factors which are aggregate type, particle size distribution, age of concrete, curing process as well as air content.

Figure 5.2 shows that gain rate of splitting tensile strength at early stage of LFC-ES10% is much drastic compared to that of LFC-CTR. The phenomenon was tally with statement by (Matschei, *et al.*, 2006). The researcher stated that calcium carbonate can enhance the hydration of C_3S which will produce a higher early strength compared to that of LFC-CTR. As for later splitting tensile strength, it is noticeable that LFC-ES10% possessed higher splitting tensile strength compared to that of LFC-CTR. This is due to the inert filler characteristic of unreacted calcium carbonate from eggshell powder enhanced the densification of microstructure of the LFC. Table 5.2 illustrates the effect on incorporation of eggshell in LFC on its splitting tensile strength at 180 days of curing period.

Table 5.2: Effect of Incorporation of Eggshell in LFC in terms of Splitting Tensile Strength at 180 Days of Curing Period

Age	Mix	Strength development of LFC-ES10% compared to that of control mix at 180days of age
180 days	LFC-CTR	100%
	LFC-ES10%	108%

5.4 Flexural Strength Test

Flexural strengths of LFC-ES10% and LFC-CTR are presented in Figure 5.3.

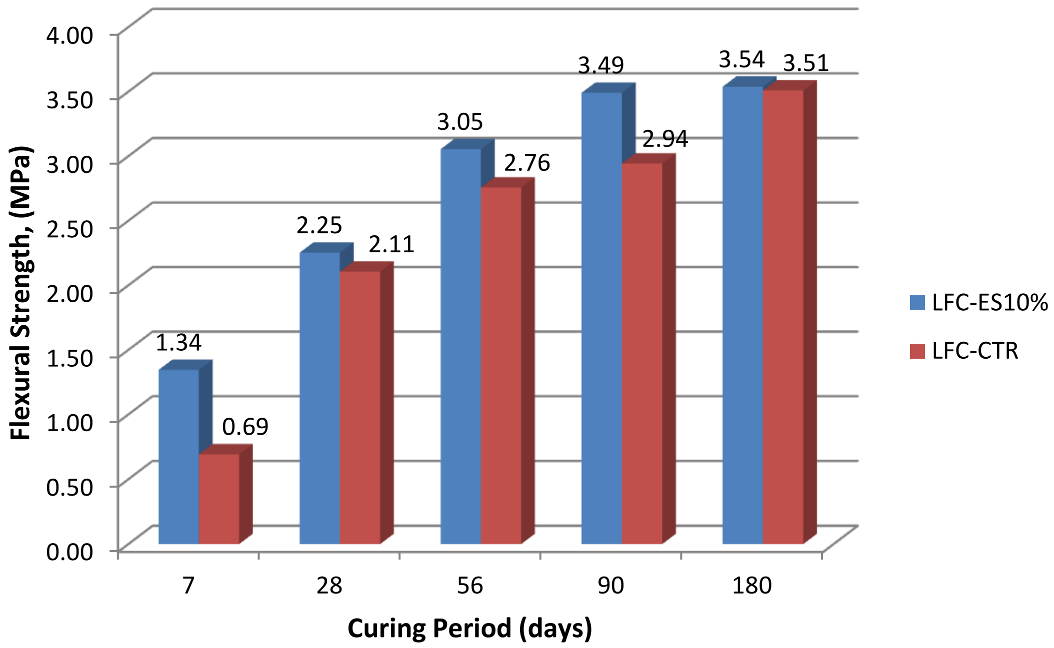

Figure 5.3: Flexural Strength Development up to 180 days of age for LFC-ES10% and LFC-CTR.

Figure 5.3 shows the flexural strength of LFC-ES10% and LFC-CTR for each curing period ranging from 7 days to 180 days. It is noticeable that flexural strengths of both LFC-ES10% and LFC-CTR increases throughout the curing periods. LFC-ES10% obtained a higher splitting tensile strength at 180 days of curing age compared to that of LFC-CTR.

Generally, similar to splitting tensile strength development, flexural strength development shares the same trend as compressive strength development. LFC-ES10% has a much higher early and later flexural strength than LFC-CTR which is again justified by Matschei, *et al.*, (2006). Table 5.3 illustrates the effect of incorporation of eggshell powder in LFC at 180 days of curing period.

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

Age	Mix	Strength development of LFC compared to that of control mix at 180days of age
180 days	LFC-CTR	100%
	LFC-ES10%	101%

5.5 Poisson's Ratio

Poisson's ratio and modulus of elasticity for LFC-CTR and LFC-ES10% are presented in Table 5.4.

Table 5.4: Poisson's Ratio & Modulus of Elasticity of LFC-CTR and LFC-ES10% for 90 days of age

Specimen Series No.	40% Strength	ε_2[1]	εt_2[2]	εt_1[3]	Poisson's Ratio, μ[4]	Modulus of Elasticity, MPa
LFC-ES10%	1.5275	0.00417	0.001532	0.0000235	0.366	370
LFC-CTR	1.0788	0.02601	0.000268	0.0000071	0.102	417

Note:

[1] ε_{t2} = tranverse strain at midheight of the specimen produced by stress corresponding to 40 % of ultimate load

[2] ε_{t1} = tranverse strain at midheight 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] $\mu = (\varepsilon_{t2} - \varepsilon_{t1})/(\varepsilon_2 - 0.000050)$

Table 5.4 shows the LFC-ES10% possessed higher 40% strength compared to that of LFC-CTR. LFC-ES10% obtained a higher value of Poisson's ratio compared to that of LFC-CTR at 90 days of curing age. Modulus of elasticity of LFC-ES10% achieved is lower compared to that of LFC-CTR. This shows that by incorporating eggshell powders as partial cement replacement material in LFC had increased the elasticity of the LFC.

5.6 Compressive Toughness

Compressive stress-strain relationships for LFC-ES10% and LFC-CTR are illustrated in Figures 5.4 and 5.5 respectively.

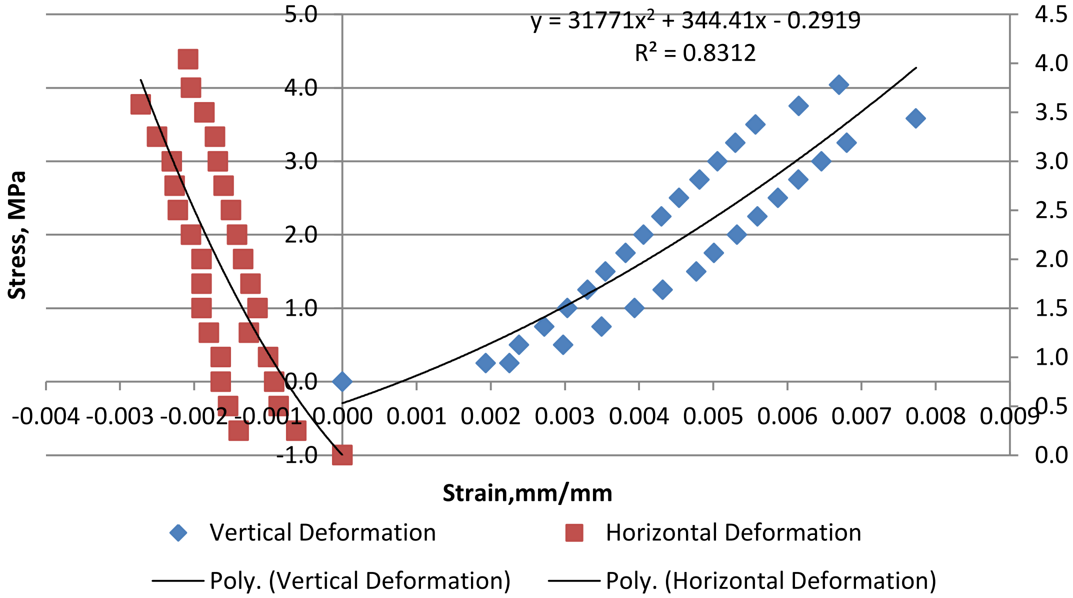

Figure 5.4: 90 days stress-strain relationship of LFC-ES10%

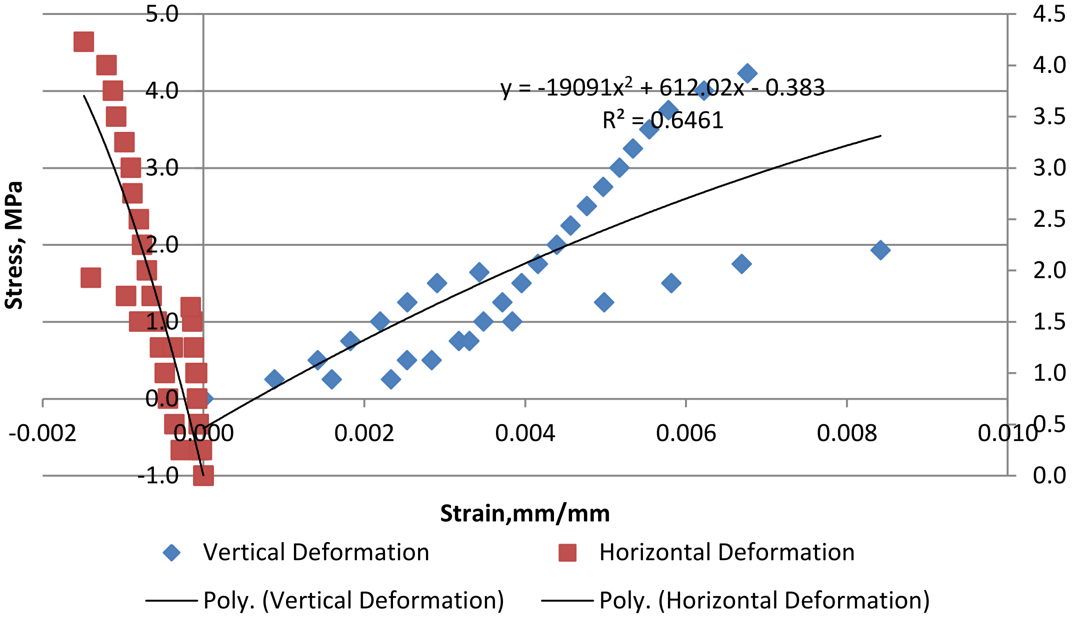

Figure 5.5: 90 days stress-strain relationship of LFC-CTR

Table 5.5: Compressive Toughness of LFC-ES10% and LFC-CTR at 90 days of age

Specimen Series No.	Curves Trend line equation	R^2	Max Compressive Strength	Compressive Toughness (J/m^3)
LFC-ES10%	$31771x^2 + 344.41x - 0.2919$	0.8312	3.95	3.98×10^{15}
LFC-CTR	$19091x^2 + 612.02x - 0.38$	0.6461	2.69	1.52×10^{15}

Table 5.5 shows the compressive toughness of LFC-ES10% and LFC-CTR at 90 days of curing age. LFC-ES10% obtained higher maximum compressive strength compared to that of LFC-CTR. Compressive toughness of LFC-ES10% was higher than LFC-CTR. Incorporation of eggshell powders as partial cement replacement material for LFC enhanced the durability of the LFC.

5.7 Performance Index

5.7.1 Performance Index of Compressive Strength

Performance indexes of compressive strength of both LFC-ES10% and LFC-CTR are presented in Figure 5.6.

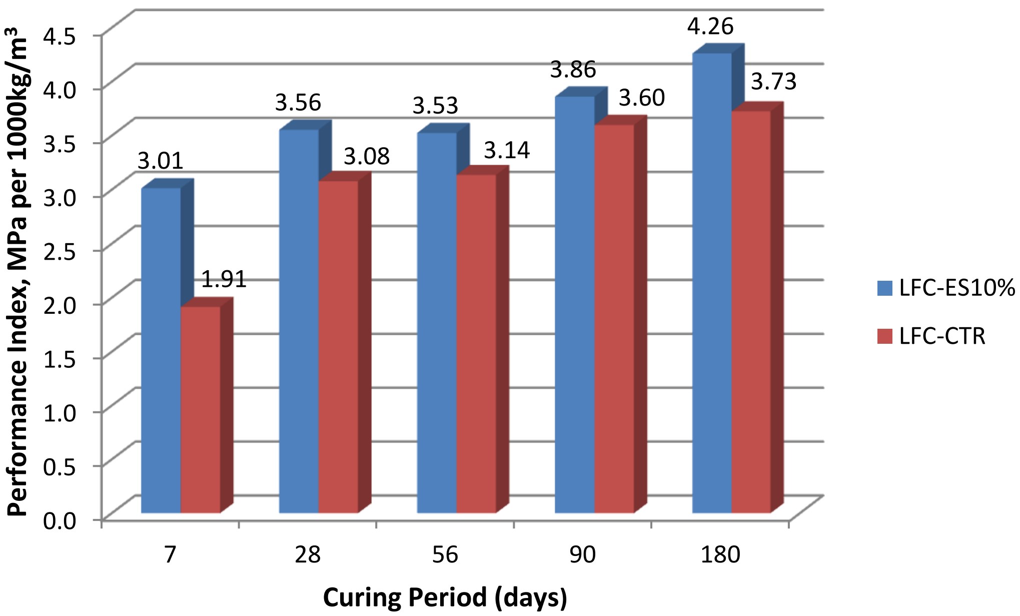

Figure 5.6: Average Performance Indexes of LFC-ES10% & LFC-CTR at 7, 28, 56, 90 and 180 days of Curing Ages.

Figure 5.6 shows the average performance indexes of both LFC-ES10% and LFC-CTR for all curing periods. Figure 5.6 shows that the performance index of both LFC-ES10% and LFC-CTR increased throughout the curing period. The performance indexes explicated that compressive strength of LFC-ES10% at all curing periods were higher than that of LFC-CTR.

5.7.2 Performance Index of Splitting Tensile Strength

Performance indexes of splitting tensile strength of both LFC-ES10% and LFC-CTR are presented in Figure 5.7.

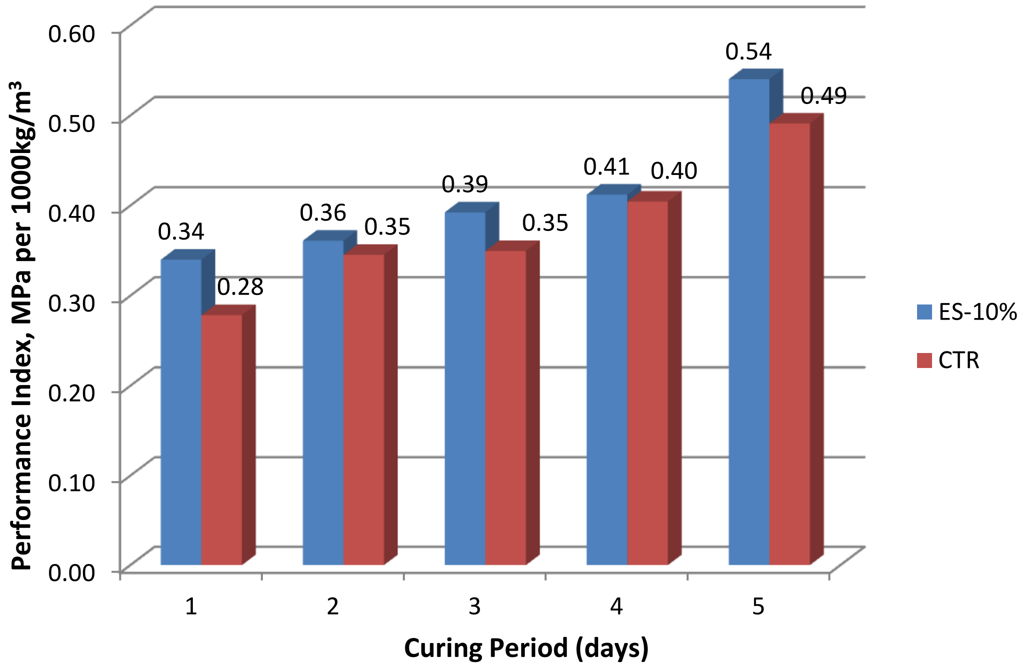

Figure 5.7: Average Performance Indexes of LFC-ES10% & LFC-CTR at 7, 28, 56, 90 and 180 of curing ages

Figure 5.7 shows the average performance indexes of both LFC-ES10% and LFC-CTR for all curing periods. Figure 5.7 shows that the performance index of both LFC-ES10% and LFC-CTR increased throughout the curing period. The performance indexes explicated that splitting tensile strength of LFC-ES10% at all curing periods were higher than that of LFC-CTR.

5.7.3 Performance Index of Flexural Strength

Performance indexes of flexural strength of both LFC-ES10% and LFC-CTR are presented in Figure 5.8.

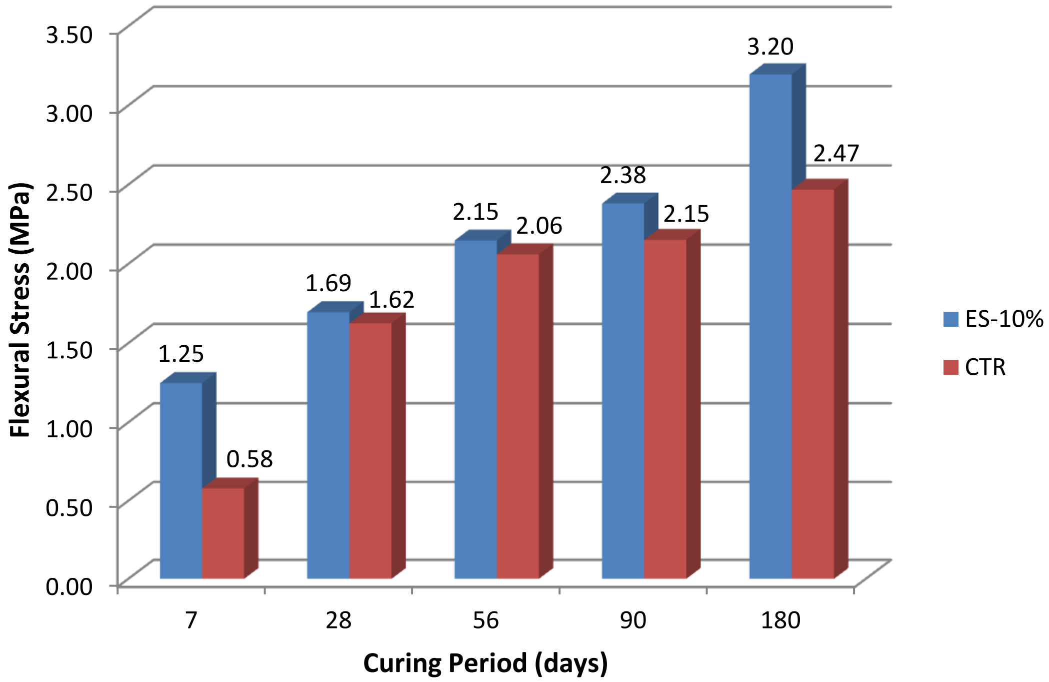

Figure 5.8: Average Performance Indexes of LFC-ES10% and LFC-CTR of 7, 28, 56, 90 and 180 of Curing Ages.

Figure 5.8 shows the average performance indexes of both LFC-ES10% and LFC-CTR for all curing periods. Figure 5.8 shows that the performance index of both LFC-ES10% and LFC-CTR increased throughout the curing period. The performance indexes explicated that flexural strength of LFC-ES10% at all curing periods were higher than that of LFC-CTR.

5.8 Summary

Incorporation of eggshell powder into lightweight foamed concrete as partial cement replacement had shown convincing results in improving the engineering properties of lightweight foamed concrete in terms of compressive, splitting tensile and flexural strength up to 180 days of age as well as 90 days compressive toughness.

LFC-ES10% possessed higher compressive, splitting tensile and flexural strength in all curing ages of 7, 28, 56, 90 and 180 days compared to that of LFC-CTR. Besides, LFC-ES10% also obtained a higher performance indexes for all 7, 28, 56, 90 and 180 days of curing ages compared to that of LFC-CTR. The results proven that incorporation of eggshell powders as partial cement replacement material in LFC can improve its compressive, splitting tensile and flexural strengths.

LFC-ES10% possessed higher Poisson’s ratio at 90 days of curing age compared to that of LFC-CTR. Besides, LFC-ES10% obtained a higher compressive toughness at 90 days of curing age compared to that of LFC-CTR.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Based on laboratory results, few conclusions can be drawn corresponding to the respective objectives that are targeted at the beginning of the study.

The First objective is to produce lightweight foamed concrete with fresh and hardened density in a range of 1250kg/m^3 to 1350kg/m^3. This was achieved as two types of foamed concrete namely LFC-CTR and LFC-ES10% as shown in Tables 4.2 and 4.4, respectively.

The Second objective is to obtain the optimal water to cement ratio for LFC-CTR and LFC-ES10%. Optimal water to cement ratio of LFC-CTR is 0.56, while water to cement ratio of LFC-ES10% is 0.60.

The Third objective is to study the effect of eggshell powder as partial cement replacement materials on fresh properties namely inverted slump value, consistency and stability. LFC-ES10% obtained lower inverted slump value compared to that of LFC-CTR. Consistency and stability of the both mixes are nearly unity. The eggshell powders seem did not have significant effect on the both properties.

The fourth objective is to study the effect of eggshell powder as partial of cement replacement material on engineering properties of lightweight foamed concrete in terms of compressive, flexural, splitting tensile strength, Poisson's ratio and compressive toughness. Incorporating of eggshell powders into lightweight foamed concrete had improved its compressive, splitting tensile and flexural strengths up to 180 days of age as well as Poisson's ratio and compressive toughness at 90 days of age.

6.2 Recommendations

The research work on lightweight foamed concrete incorporated with eggshell powder is still limited. Nonetheless it promises a great scope for further studies. Following aspects that related to the properties of lightweight foamed concrete are suggested for further study.

1. The effect of higher replacement percentage of eggshell powder in LFC on its various engineering properties.
2. The effect of other curing methods on various engineering properties of LFC.
3. The effect of eggshell powder on acoustic properties and thermal conductivity of LFC.

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APPENDICES

APPENDIX A: Compressive Strength, Splitting Tensile Strength and Flexural Strength of Various LFC Specimen

Age (days)	Mix	Compressive Strength (MPa)	Splitting Tensile Strength (MPa)	Flexural Strength (MPa)
7	LFC-CTR	2.4708	0.4315	0.6918
	LFC-ES10%	3.3043	0.4411	1.3448
28	LFC-CTR	3.8719	0.4607	2.1056
	LFC-ES10%	4.9943	0.5209	2.2525
56	LFC-CTR	4.7805	0.5144	2.7579
	LFC-ES10%	5.1994	0.5649	0.5649
90	LFC-CTR	4.9883	0.5522	2.9429
	LFC-ES10%	5.5922	0.6702	3.4911
180	LFC-CTR	5.4719	0.6824	3.5092
	LFC-ES10%	5.9310	0.7389	3.5383

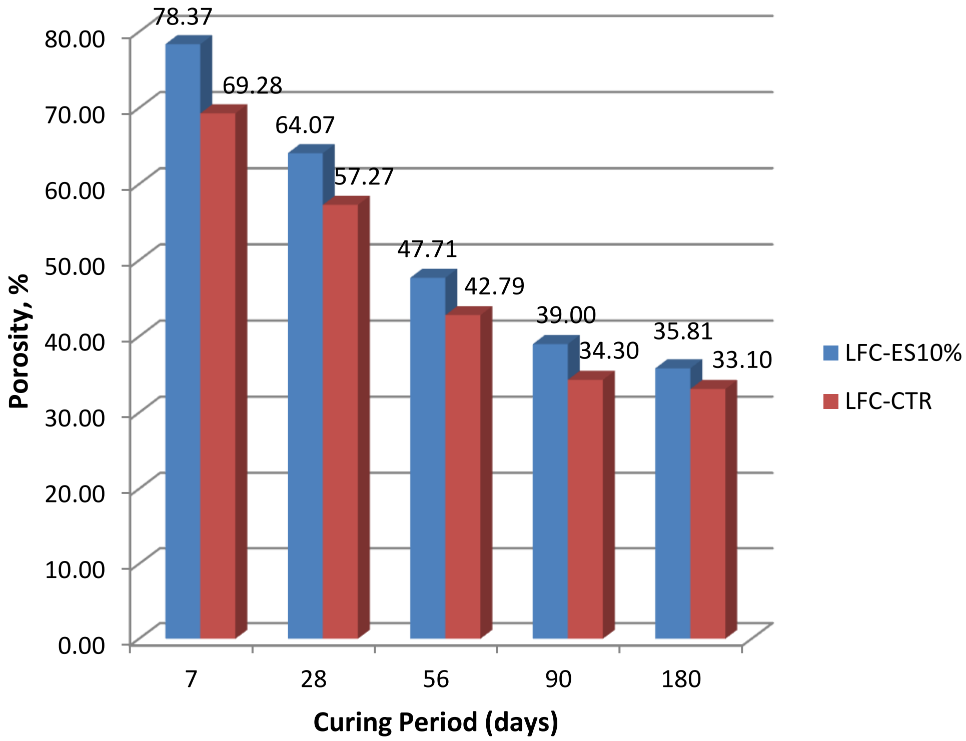
APPENDIX B: Performance Index of Compressive Strength, Splitting Tensile Strength and Flexural Strength of Various LFC Specimens.

Age (days)	Mix	PI for Compressive Strength (MPa)	PI for Splitting Tensile Strength (MPa)	PI for Flexural Strength (MPa)
7	LFC-CTR	1.9141	0.2783	0.5792
	LFC-ES10%	3.0133	0.3399	1.2471
28	LFC-CTR	3.0792	0.3453	1.6244
	LFC-ES10%	3.5550	0.3609	1.6947
56	LFC-CTR	3.1360	0.3496	2.0597
	LFC-ES10%	3.5256	0.3925	2.1475
90	LFC-CTR	3.5993	0.4045	2.1511
	LFC-ES10%	3.8620	0.4121	2.3804
180	LFC-CTR	3.7251	0.4910	2.4679
	LFC-ES10%	4.2625	0.5403	3.1952

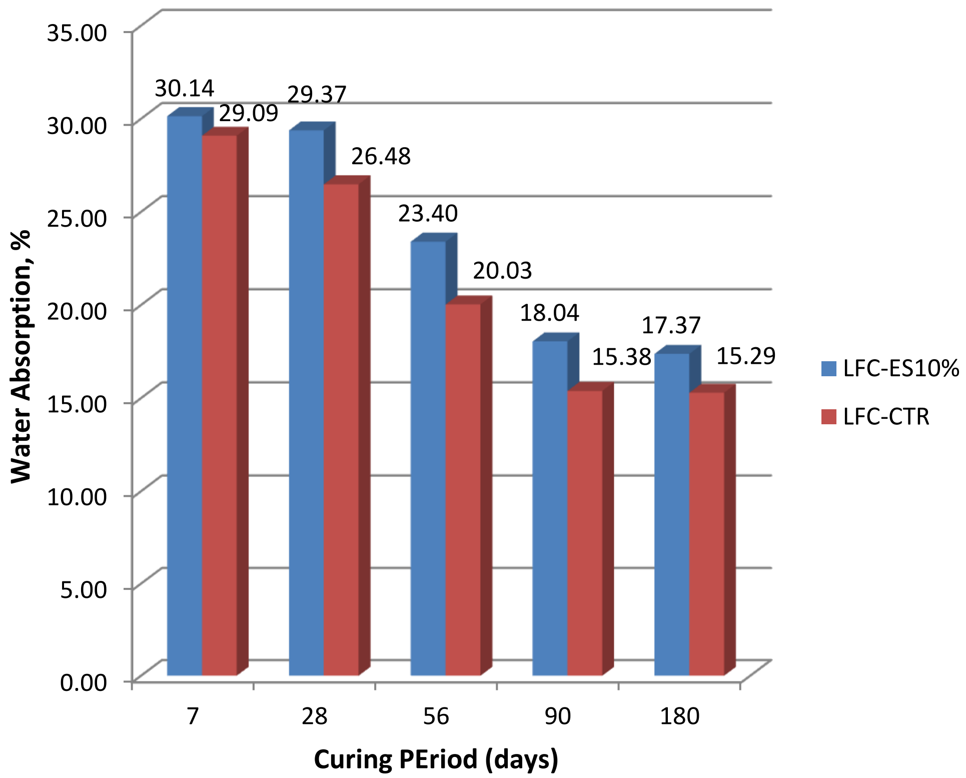
APPENDIX C: Porosity and Water Absorption of Various LFC Specimens

Age (days)	Mix	Porosity, %	Water Absorption, %
7	LFC-CTR	69.28	29.09
	LFC-ES10%	78.37	30.14
28	LFC-CTR	57.27	26.48
	LFC-ES10%	64.07	29.37
56	LFC-CTR	42.79	20.03
	LFC-ES10%	47.71	23.40
90	LFC-CTR	34.30	15.38
	LFC-ES10%	39.00	18.04
180	LFC-CTR	33.10	15.29
	LFC-ES10%	35.81	17.37

APPENDIX D: Porosity of LFC-ES10% and LFC-CTR up to 180 days of age



APPENDIX E: Water absorption of LFC-ES10% and LFC-CTR up to 180 days of age



APPENDIX F: Consumption of Lifestock Products 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**	**6,793**	**7,107**	**7,157**	**7,300**	**7,887**	**8,572**	**8,980**	**9,354**	**9,403**
		**** 388**	**** 408**	**** 426**	**** 429**	**** 438**	**** 473**	**** 514**	**** 539**	**** 561**	**** 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*