WATER ABSORPTION AND STRENGTH PROPERTIES OF LIGHTWEIGHT FOAMED CONCRETE WITH 2.5 % AND 5.0 % EGGSHELL AS PARTIAL CEMENT REPLACEMENT MATERIAL

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

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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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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"WATER ABSORPTION AND STRENGTH PROPERTIES OF LIGHTWEIGHT FOAMED CONCRETE WITH 2.5 % AND 5.0 % EGGSHELL AS PARTIAL CEMENT REPLACEMENT MATERIAL"** was prepared by **LEE REN SIONG** 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.

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Specially dedicated to

my beloved family

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ABSTRACT

Eggshell is a solid waste that commonly generated in huge quantities from our daily life. Disposal of eggshell has created a lot of environmental problems due to its reusability of material is low in many industries. Recent years, researchers have found that the valuable of eggshell due to its high content of calcium carbonate. Consequently, it has encouraged the researchers to incorporate the eggshell with lightweight foamed concrete while contributing to sustainable development of building materials. This experimental study is aimed to investigate the effects of incorporation of eggshell on its water absorption and strength properties of lightweight foamed concrete (LFC) with density of 1300 kg/m^3 in terms of initial surface absorption, sorptivity, water absorption, porosity, compressive strength as well as ultrasonic pulse velocity (UPV). Three types of lightweight foamed concrete were prepared, namely i) LFC with 0% eggshell powder replacement as control mix (LFC-CTR); ii) LFC with 2.5% eggshell powder replacement (LFC-ES2.5); iii) LFC with 5.0% eggshell replacement (LFC-ES5.0). A water to cement ratio of 0.56 was adopted to study the development of water absorption and strength properties on LFC-CTR, LFC-ES2.5 and LFC-ES5.0 at 7 days, 28 days and 90 days of ages throughout the study. All the specimens were water cured before being tested. The laboratory results showed that the incorporation of eggshell powder into lightweight foamed concrete has decreased its initial surface absorption, sorptivity, water absorption as well as porosity; while increased its compressive strength as well as ultrasonic pulse velocity (UPV).

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LIST OF SYMBOLS / ABBREVIATIONS

A	cross-sectional area of specimen which load applied, mm^2
a	exposed area of the specimen, mm^2
d	density of water, g/mm^3
Div	number of scale of division during the period, units
f	flow, $ml/m^2/s$
f_c	compressive strength, MPa
I	sorptivity, mm
m_t	the change in specimen mass at the time, g
P	maximum load sustained by specimen, N
PI	performance index, MPa per 1000 kg/m^3
P_r	porosity of hardened concrete specimen, %
Sor	sorptivity coefficient, $mm/s^{0.5}$
t	period, s
t_{us}	transit time, µs
$\sqrt{t}$	square root of time measured at which the mass is determined, $s^{0.5}$
V	pulse velocity, km/s
W.A.	water absorption of hardened concrete specimen, %
W_{dry}	oven dried weight of specimen, kg
W_{sat}	saturated surface dry weight of specimen, kg
W_{wat}	weight of specimen in water, kg
x	length of path travelled, mm
ASTM	American Society for Testing and Materials
BS	British Standard
C-S-H	calcium silicate hydrate
ISAT	initial surface absorption test
LFC-CTR	lightweight foamed concrete with 0% of eggshell powder

LFC-ES2.5	lightweight foamed concrete with 2.5% of eggshell powder
LFC-ES5.0	lightweight foamed concrete with 5.0% of eggshell powder
OPC	ordinary Portland cement
UPV	ultrasonic pulse velocity
W/C or w/c	water to cement ratio

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CHAPTER 1

INTRODUCTION

1.1 Introduction

This study presents the feasibility of eggshell as a partial cement replacement material in lightweight foamed concrete (LFC). The main purpose of this paper is to study water absorption and strength properties of lightweight foamed concrete with eggshell as partial cement replacement. Lightweight foamed concrete is one of the oldest manufactured construction materials that started its application on various structures since ancient day. It was first introduced by the Romans in the second century where 'The Pantheon' was constructed by using pumice (Mohd Roji Samidi, 1997). Nowadays, lightweight foamed concrete has been developed into various concrete types over the years. The lightweight foamed concrete also known as aerated concrete, due to its versatilities and lightness, has brought an alternative offer application of economic building material for building technology. Lightweight foamed concrete is a versatile material that has a concrete density range from 300 kg/m³ to 1850 kg/m³ (Neville, 2010). Lightweight foamed concrete with density of 1200 – 1600 kg/m³ is used in precast panels of any dimension for commercial and industrial use, in-situ casting of walls, garden ornaments and other uses (Olarewaju *et al.*, 2011).

The usage and application of LFC in construction field is now increasing due to the advantages it possesses, for example, prefabricated walls, sound barrier walls, wall panels, floor trays, and etc. Besides, by using the LFC, it helps to reduce the building dead load and resulting in more economic structural design (Short & Kinniburgh, 1978; Narayanan & Ramamurthy, 2000).

For the consideration of building materials cost, lightweight foamed concrete is incorporated with other applicable waste material nowadays. Palm oil fuel ash is used as filler in lightweight foamed concrete to increase its mechanical strength properties (Lim *et al.*, 2013). The value of research is foreseeable for lightweight foamed concrete. Lightweight foamed concrete is improved in ecological manner while maintaining their significant properties toward creating sustainable building materials.

1.2 Problem Statement

Eggshell is a food solid waste that generates from food industry, for examples, restaurants, bakeries, and etc. These food industries are constantly accumulating bulk and substantial quantities of eggshell waste. Over 50 million cases of eggs (at 30 dozen eggs to the case) are used annually by the food industry (Sonenklar, 1999). In recent year, as cited from Shuhadah (2008), around 150 000 tons of eggshell waste is disposed in landfills (Hussien, 2013). It is logical to deduce that the eggshell waste increases significantly as the populations grow. In certain case, companies pay up to 100 000 dollars to dispose of eggshell waste in landfills and consequently the landfills reaching its capacity (Sonenklar, 1999). Based on the statistics from Malaysia Veterinary Department (DVS), the consumption of eggs in year 2013 was 9551 million eggs with an increasing trend of about 400 million per year. By year 2014, the consumption of eggs was increased to 9922 million eggs and expected to increase in coming years (DVS, 2014). This natural solid waste has creates a huge problem of pollution in the environment. Moreover, the eggshell waste can attract vermin and rats due to its protein rich membrane, resulting in a problem of public health. Nowadays, eggshell waste has brings an important issue on solid waste environmental problem that requires public attention.

Recent years, waste recycling practices are encouraged among engineering industry to enhance sustainability. Eggshell waste is involved in the development of innovative technology in various industries. Eggshell waste is calcining and used as a solid catalyst in biodiesel synthesis, resulting in creates cost effective products (Wei *et al.*, 2009). Furthermore, there is a research on the effect of eggshell powder on the stabilizing potential of lime on expansive clay. The findings showed that the organic compound of eggshell has reduced the binding effect of calcium and potassium that could have increased the cohesion and internal angle of friction of the soil considerably (Amu *et al.*, 2005). Eggshell ash also used as accelerator for cement-bound materials in order to perform its effect on strength properties of cement-stabilized lateritic soil (Okonkwo, 2012).

The eggshell waste powder is rich in calcite ($CaCO_3$) and consists of porous irregular particles whose sizes from 2 to 900µm, can be used as an alternative material for wall tile production (Freire & Holanda, 2006). From this research, it showed that the eggshell waste has a pure relatively natural carbonate based material, as well as its composition is very similar to the calcitic calcareous, which can minimise the usage of the cement.

Therefore, this research conducts the experimental study on the effects of eggshell as a cement replacement material that incorporated in lightweight foamed concrete. The water absorption and strength properties, either their relationship, are measured and studied.

1.3 Objectives of Study

The objectives of this research are listed as below:

1. To produce and achieve the density of 1300 ± 50 kg/m^3 for all lightweight foamed concrete specimen at w/c of 0.56.

2. To study the effect of eggshell powder as partial cement replacement on strength and durability properties of lightweight foamed concrete in terms of initial surface absorption, sorptivity, water absorption, porosity, ultrasonic pulse velocity and compressive strength.

3. To establish the relationship between compressive strength-ultrasonic pulse velocity and compressive strength-porosity of lightweight foamed concrete incorporated with eggshell powder as partial cement replacement material.

1.4 Scope of Research

This study concentrates on the effects of eggshell as partial cement replacement on durability properties of lightweight foamed concrete in terms of initial surface absorption, sorptivity, water absorption, porosity, ultrasonic pulse velocity and compressive strength. The scope of works in this research are basically divided into 3 major parts, (1) specimen preparation, (2) properties testing procedure, and (3) results analysis.

Preparation of raw materials was done based on ASTM standard and requirements. The materials were well-handled and stored in a proper storage facility. Trial mix is not required in this study as the optimal w/c ratio is constant at 0.56 for this research. The targeted density of the lightweight foamed concrete is 1300 kg/m^3 with tolerance of ± 50 kg/m^3. Three types of lightweight foamed concrete were prepared, namely i) LFC with 0% eggshell powder replacement as control mix; ii) LFC with 2.5% eggshell powder replacement; iii) LFC with 5.0% eggshell replacement. During preparation of the LFC specimens, flow table test were carried out to measure the consistency and workability of the fresh concrete respectively.

Cubic and cylindrical specimens were cured in water and tested for 7 days, 28 days and 90 days initial surface absorption, sorptivity, water absorption and porosity respectively. Cubic specimens were used to carry out ultrasonic pulse velocity test and followed by compressive strength test.

1.5 Significance of Research

The significances of this study are as follows:

1. Incorporating eggshell powder as partial cement replacement in the mix as to encourage the use of solid waste and create more sustainable environment besides its own ability to reduce water absorption and enhance strength properties of the concrete.

2. Developing the mix proportion to produce lightweight foamed concrete incorporated with eggshell powder and studies strength and durability properties in terms of initial surface absorption, sorptivity, porosity, water absorption, ultrasonic pulse velocity and compressive strength.

1.6 Layout of the Report

Chapter one outlines an introduction for this research, problem statements or relevant issues pertaining to the objective of this research. The background information of this study and undertaking, prior researches that were carried out in the literature review are briefly described. Besides, scope of work and significance of this research are elaborated.

Chapter two outlines the relevant literature review and research of lightweight foamed concrete with eggshell replacement. Findings and results that related to the literature review are included for clarity and are used as a basis to formulate hypothesis of this undertaking. This chapter gives general description of materials used such as eggshell powder, sand, cement and foam. Besides, the properties of LFC are discussed in this chapter.

Chapter three presents the research methodologies applied in this study. The material preparations, mixing procedures, techniques, tools/apparatus, and the standard cited used are discussed in this chapter. Compliance to the prevailing and conventional standard, such ASTMs are strictly complied and duly observed in the laboratory practices. Besides, testing methods on specimen are discussed in this chapter.

Chapter four discusses the laboratory results of lightweight foamed concrete incorporated with eggshell as partial cement replacement material in terms of initial surface absorption, sorptivity, water absorption and porosity.

Chapter five discusses the laboratory results of lightweight foamed concrete incorporated with eggshell as partial cement replacement material in terms of compressive strength and ultrasonic pulse velocity.

Chapter six summarizes and concludes the study based on the results obtained. The conclusions are made respectively according to the objectives of this experimental study. Recommendations are given for further improvement and development of lightweight foamed concrete.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Lightweight foamed concrete is a mixture of Ordinary Portland Cement, fine aggregate, water and foam, which has a pore structure that caused by artificial air voids. Foaming agent is applied and entrained into cement mortar in order to create artificial air bubbles, resulting in lighter weight of LFC as compared to normal concrete (Ramamurthy *et al.*, 2009).

Development of lightweight foamed concrete incorporated with cementitious materials is studied nowadays in order to investigate its properties. Cementitious materials such as fly ash, rice husk and eggshell powder are incorporated with concrete in order to study its compressive strength (Jayasankar *et al.*, 2010; Chirag *et al.*, 2013).

In this chapter, the durability properties of lightweight foamed concrete incorporated with eggshell powder are reviewed in accordance to appropriate journals and articles. The relevant researches are also being reviewed in this chapter. In addition, the properties and characteristics of raw materials that utilised in this study are discussed in accordance with competent standard.

2.2 Advantages of Lightweight Foamed Concrete

The application of lightweight foamed concrete is increases among construction industries nowadays due to its advantages. Lightweight foamed concrete has high workability, low dead load, and provides thermal insulation properties (Ramamurthy *et al.*, 2009). The reduction of dead load of lightweight foamed concrete has lead to cost savings. High workability of lightweight foamed concrete has its advantage in application of void filling. Nevertheless, lightweight foamed concrete with porous structure performs high acoustics shielding properties and thermal insulation properties (Kim *et al.*, 2012). In terms of durability, lightweight foamed concrete has small deterioration with time; and is a durable material which acts like a rock (Gambhir, 2013).

2.3 Durability of Concrete

Durability of concrete plays a critical role in controlling its serviceability. Other than mechanical properties, durability is one of the important aspects in recent years. A durable concrete will retain its original form, quality, and serviceability when exposed to its service environment (Gambhir, 2013). Other than adverse physical and chemical effects, the durability of concrete depends on its microstructure such as porosity and permeability. Permeability is the capacity of a fluid to penetrate the concrete. High permeability led to the introduction of molecules that react and destroy its chemical stability (Mehta & Monteiro, 2014).

High porosity of concrete is easily being attacked by deterioration agent and resulted in lower strength. However, porous structure such as foamed concrete has a considerable durability due to its resistance to freeze-thaw action; it is durable as a rock (Gambhir, 2013).

2.4 Water as an Agent of Deterioration

Water is an important raw material for mixing concrete. It gives an important role in cement hydration process which helps the production of C-S-H gel. Water is the most abundant fluid in nature which exists in various states. Regardless of its significant role, the water is an agent of deterioration which permeates concrete (Mehta & Monteiro, 2014).

Water molecules are very small which enable it to penetrate into very fine pores and cavities. Furthermore, water is possessed of the highest heat of vaporization among the common fluids. At ambient temperature, water tends to exist in liquid state in a porous material rather than vaporizing and leaving the material dry. The internal movement of moisture and structural transformation of water within porous solids are known to inflict disruptive volume changes. For instance, the mechanism of water freezing into ice, development of osmotic pressure due to concentration gradient, and hydrostatic pressure build up by differential vapour pressure can lead to high internal stress. Hence, high internal stress leads to the expansion inside the concrete. In this study, water was used as a testing agent for initial surface absorption test, sorptivity test, porosity and water absorption test (Mehta & Monteiro, 2014).

2.5 Pore System and Permeability of Concrete

Generally, quality of concrete with respect to durability is related to its characteristics of pore system which measured in term of permeability (Gambhir, 2013; Schutter & Audenaert, 2004).

As cited from Hilal *et al.* (2015), due to the dependence on material porosity and permeability, the cementitious material gives a important pore structure characteristic since it affects durability and strength properties (Ramamurthy *et al.*, 2009). The more porous the concrete, the material is more susceptible to degradation mechanism caused by penetrating substances for example, water (Schutter & Audenaert, 2004). The penetration is aided by the internal transport of agents by diffusion due to internal gradients of moisture and temperature and by osmosis (Neville & Brooks, 2010).

Concrete with low porosity and permeability will resist undesirable phenomena. Gambhir (2013) mentioned that the porosity is governed by porosity. The pores in cement paste consist of gel pores and capillary pores. Due to the capillary pores are larger in size than gel pores, the permeability of cement paste is governed by the capillary porosity as shown in Figure 2.1 (Gambhir, 2013).

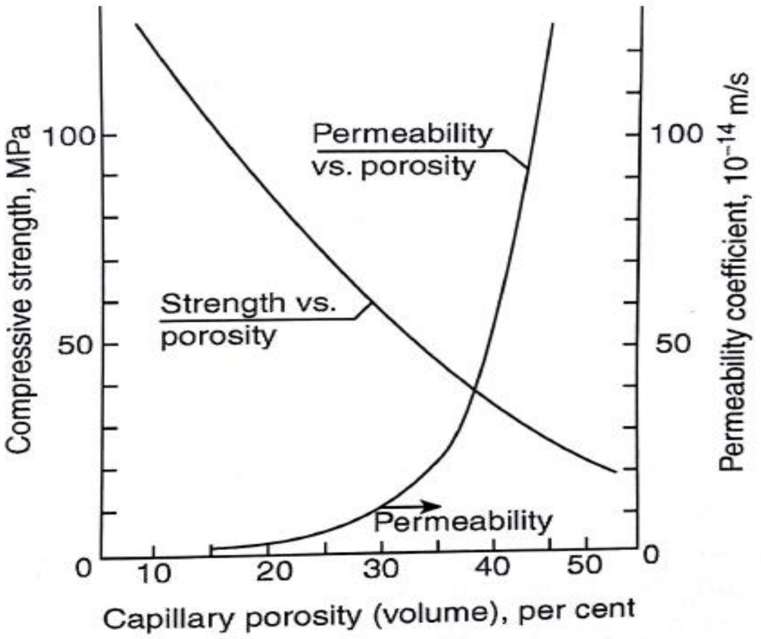
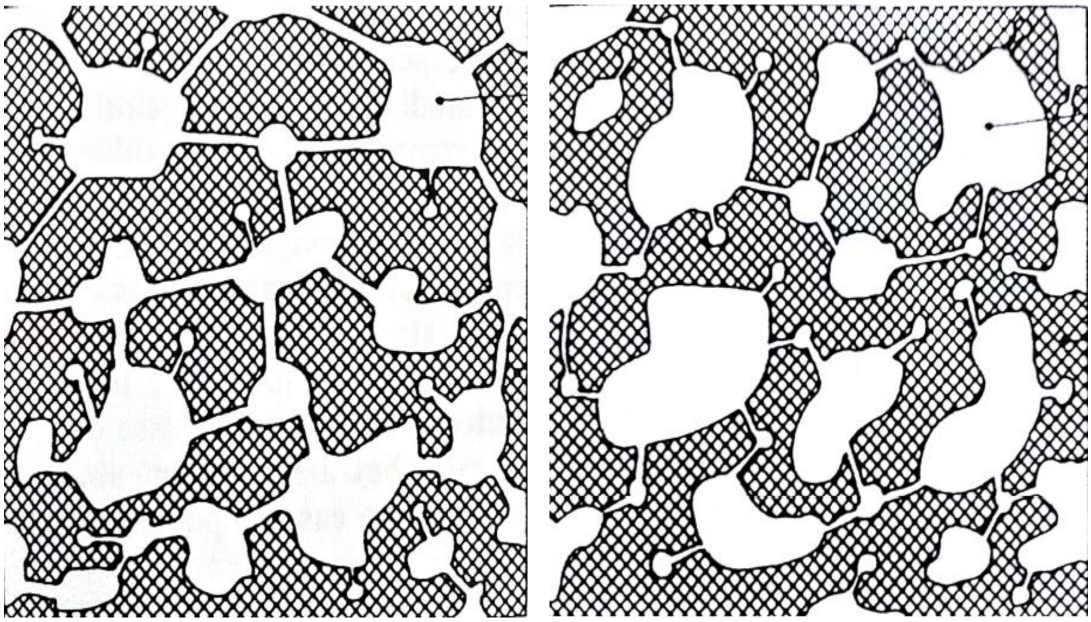


Figure 2.1: The Relationship between Compressive Strength and Porosity; & Permeability and Porosity (Gambhir, 2013)

In another view, permeability is not a simple function of porosity. It is possible for two porous concretes to have same porosity but different permeability as shown in Figure 2.2. The segmenting of capillaries is influenced largely on its permeability (Neville & Brooks, 2010). If the large capillary pores are interconnected, then it will result in high permeability. The research showed that the result from water absorption test gives an estimation of the total pore volume of the concrete, but the concrete permeability cannot be indicated (Schutter & Audenaert, 2004). As cited from Ramamurthy *et al.* (2009), the water absorption of foamed concrete is mainly affected by paste phase but not entrained pores which are not interconnected.



(a) High permeability – capillary pores (non shaded region) interconnected by large passages.

(b) Low permeability – capillary pores segmented and only partly connected.

Figure 2.2: Schematic Representation of Materials of Similar Porosity Around C-S-H (Shaded Region) but: (a) High Permeability and (b) Low Permeability (Neville & Brooks, 2010)

2.6 Relationship between Water Absorption and Sorptivity

Sorptivity is the water ingress of unsaturated porous concrete due to surface tension dominated by capillary suction and is a function of the pore structure of the porous concrete (Jayeshkumar & Umrigar, 2013). Sorptivity test is necessary in order to determine the rate of water absorption of capillary suction since the driving force for water absorption test is only response to pressure (Jayeshkumar & Umrigar, 2013).

Previous study opined that the effect of eggshell as partial cement replacement has increased its water absorption with increased sorption as shown in Figure 2.3 (Yerramala, 2014). From this study, it also found that sorption decreases with strength properties. Another similar study also opines that the effect of fly ash has increased its water absorption with increased sorptivity (Jayeshkumar & Umrigar, 2013).

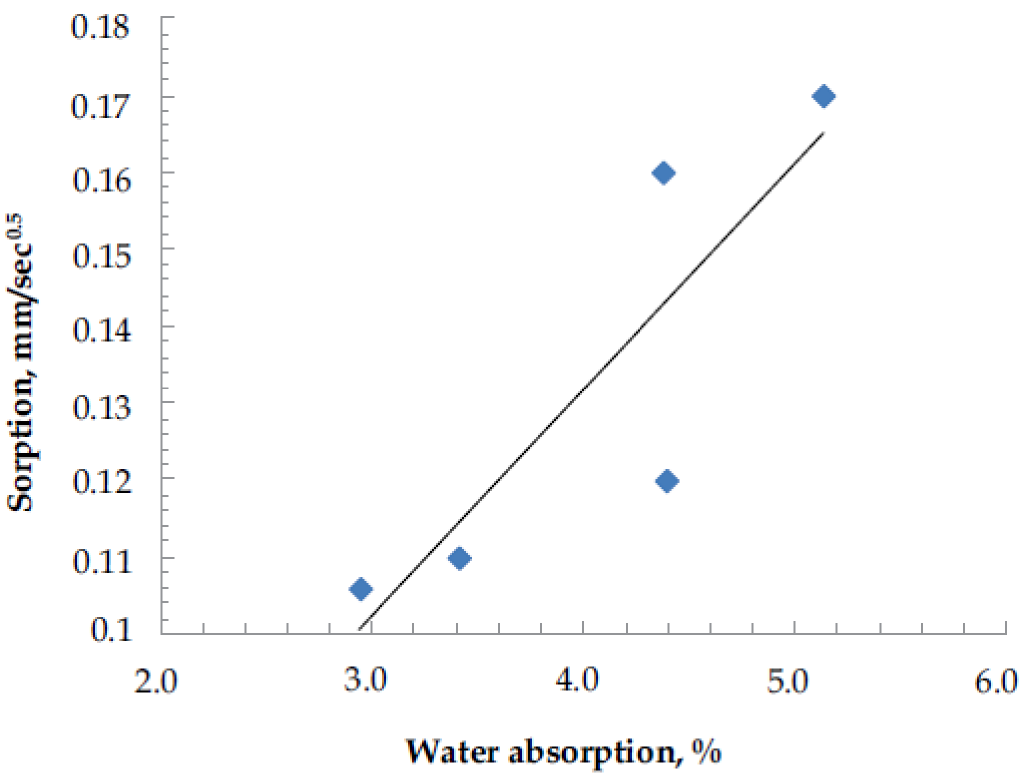


Figure 2.3: Relationship between Water Absorption and Sorptivity (Yerramala, 2014)

2.7 Relationship between Water Absorption and Porosity

The study had shown that 5 % and 10 % eggshell powder as partial cement replacement has lower water absorption than control concrete whereas further increased replacement shows same water absorption with control concrete

(Yerramala, 2014). Furthermore, it also observed that the water absorption increases with increased porosity as shown in Figure 2.4 (Yerramala, 2014).

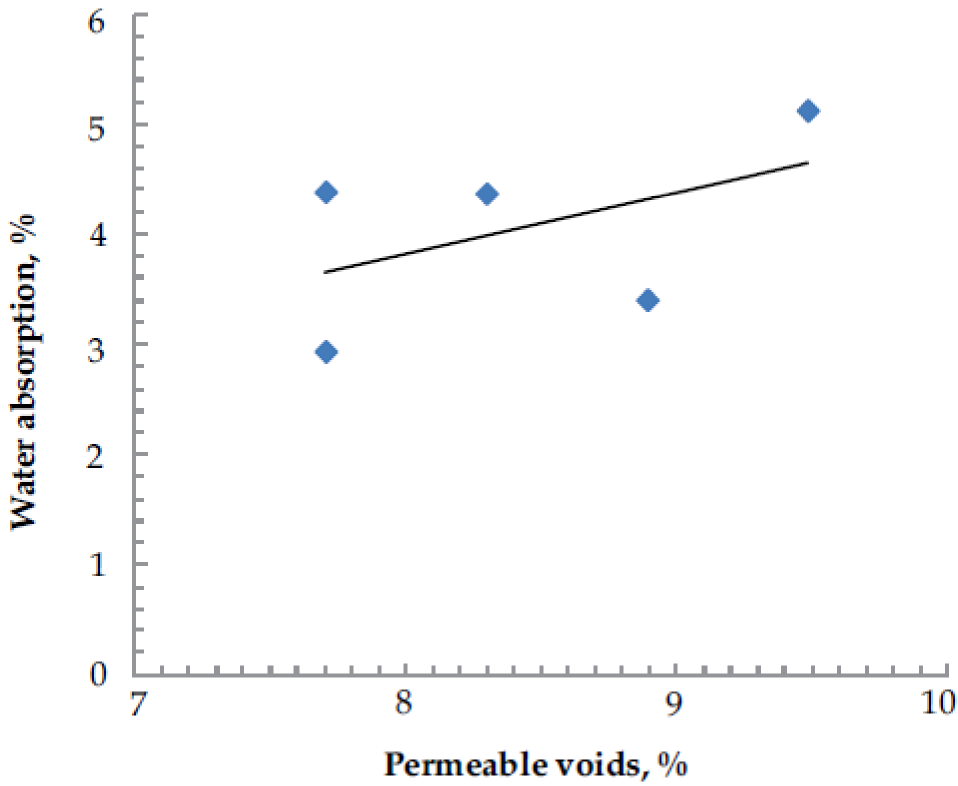


Figure 2.4: Relationship between Water Absorption and Porosity (Yerramala, 2014)

2.8 Relationship between Strength and Porosity

Generally, there exists a fundamental inverse relationship between porosity and strength of solids (Mehta & Monteiro, 2014). The porosity can be related to strength in hardened cement paste.

Ramamurthy *et al.* (2009) mentioned that the importance of air-void influencing the strength of foamed concrete and concluded that foamed concrete with a narrower air-void size distribution shows higher strength. Therefore, the smaller size of air void gives less porosity which results in higher strength.

A good correlation was observed between strength and sorptivity from previous study. As the strength of concrete increased due to hydration, thus the sorptivity reduced significantly indicating a denser microstructure (Bozkurt & Yazicioglu, 2010).

Another research found that the Portland-limestone cements enhance the strength and reducing the porosity. It was explained that the limestone portion reacts with the alumina phases of cement and produces monocarboaluminates, which would contribute to the strength (Ramezanianpour & Hooton, 2014).

2.9 Correlation between Compressive Strength and Ultrasonic Pulse Velocity

The pulse velocity cannot be used as a general indicator of compressive strength because of the factor of its aggregate (Neville & Brooks, 2010).

Regardless of the factor of its aggregate, the strength of concrete has direct relation with the pulse velocity for well compacted concrete (Nayak & Jain, 2012). The relationship between ultrasonic pulse velocity (UPV) and compressive strength has found exponential for mineral admixture mortars, both UPV and compressive strength are low at early stages but increases as the curing period increases (Gül *et al.*, 2006).

The inclusion of ferrochrome ash and lime as partial cement replacement has confirmed a strong relationship between compressive strength with water permeability and ultrasonic pulse velocity whereby low water permeability gives increment of both compressive strength and ultrasonic pulse velocity (Acharya & Patro, 2015).

In structural lightweight concrete, the study has found that the relationship between compressive strength and UPV are tends to be less affected by the aggregate volume than normal weight concrete. Furthermore, in lightweight concrete with more porous aggregates and rich mortars, there is a greater relative variation of UPV than compressive strength (Bogas *et al.*, 2013).

Further discussion on compressive strength, 5 % eggshell as partial cement replacement has shown higher strength than control concrete at 7 and 28 days of curing ages (Yerramala, 2014).

2.10 Ordinary Portland Cement

Ordinary Portland Cement (OPC) is classified as Type I cement in accordance with ASTM C150 (2004). OPC is the most widely used cement in general concrete construction when there is no exposure to sulphates in soil or groundwater (Neville & Brooks, 2010).

2.10.1 Chemical Composition of Portland Cement

Generally, the actual chemical compositions and proportions of Portland cement are varying due to different manufacturers. A general composition of Portland cement is shown in Table 2.1, which indicates the oxide composition limits of Portland cements.

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

2.10.2 Compound Composition of Portland Cement

Generally, four major raw materials used in manufacturing Portland cement mainly are lime, silica, alumina and iron oxide, which usually regarded as major constituents of cement. The compound composition of Type I Portland cement is shown in Table 2.2.

Table 2.2: Typical Average Values of Compound Composition of Type I Portland Cement (Neville & Brooks, 2010)

Name of Compound	Oxide Composition	Abbreviation	Compound Composition, %
Tricalcium Silicate	$3CaO.SiO_2$	C_3S	59
Dicalcium Silicate	$2CaO.SiO_2$	C_2S	15
Tricalcium Aluminate	$3CaO.Al_2O_3$	C_3A	12
TetracalciumAluminoferrite	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF	8
Calcium Sulphate	$CaSO_4$		2.9
Free Calcium Oxide	Free CaO		0.8
Magnesium Oxide	MgO		2.4
	Loss on ignition		1.2

2.11 Foam

According to Nambiar and Ramamurthy (2007), the introduction of pores inside lightweight foamed concrete can be achieved mechanically either by pre-foaming method (produce the foam before adding it to the mix) or mix foaming method (mixing in a foaming agent). In mixed foaming, base mix with low water content is too dry, causing the burst out of the bubble in foamed concrete and hence affect the density and strength of the lightweight foamed concrete (Ramamurthy *et al.*, 2009). Furthermore, Ramamurthy *et al.* (2009), mentioned that the importance of air-void influencing the strength of foamed concrete and concluded that foamed concrete with a narrower air-void size distribution shows higher strength.

Prior to produce of foamed concrete, stable foam with density of 45 kg/m^3 is produced by using dry pre-foaming method (Aldridge, 2005). The foam must be stable in order to resists the pressure of the mortar and hold until a strong skeleton of concrete is built up around the void filled with air (Koudriashoff, 1949).

2.12 Eggshell

The eggshell is composed of a foamy layer of cuticle, a calcite or calcium carbonate layer, and two shell membranes which includes 7,000-17,000 funnel-shaped pore canals distributed unevenly on the shell surface for exchange for water and gases (Dennis *et al.* 1996). A microstructural analysis has reveals that the eggshell particles are consist of porous irregular shape (Hassan & Aigbodion, 2013). It can be concluded that the eggshell is made up of porous structure. Eggshell powder has been used as a cementitious material in the study of Chirag *et al.* (2013).

2.12.1 Chemical Composition of Eggshells

Calcium oxide is the most abundant component in eggshell which associates the presence the calcium carbonate (Freire & Holanda, 2006). The chemical composition of eggshell is shown in Table 3.2. The other composition such as silicon dioxide, aluminium oxide, ferric oxide, magnesium oxide, sodium oxide, strontium oxide, nickel oxide, phosphorus oxide and sulphur oxide are less than 1.5% of total composition. A study found that the calcium, magnesium and phosphorus contents of eggshell are 2.21, 0.02 and 0.02 g/egg respectively, which shows that the calcium is the main components in the eggshell (Sugino *et al.*, 1997). Nevertheless, eggshell matrix consists primarily 97% of calcium carbonate in the form of calcite crystals (Nys *et al.*, 1999; Mtallib & Rabiu, 2009). Froning & Bergquist (1990) mentioned that in order to prevent depletion of lime content, the eggshell shall be grounded within two days after obtained from the sources.

2.12.2 Eggshell as a Partial Cement Replacement in Normal Weight Concrete

A research has opined that eggshell powder mixed cubes when added with the grades above M25 may result in the decrease of compressive strength level. However, the concrete incorporated with eggshell powder has possesses equal strength with conventional concrete cubes (Jayasankar *et al.*, 2010). The usage of cement can be minimized by introducing the incorporation of eggshell powder.

2.13 Summary

Lightweight foamed concrete is made of a mixture which consists of fine aggregates, cement, water and foam. It can either be produced by pre-foaming method or mixed foaming method. Lightweight foamed concrete is incorporated with cementitious material in order to save cost and maintain its quality.

Eggshells which contain high percentage of calcium carbonate and calcium oxide are become an alternative waste material that can be reused in construction field. Eggshells are incorporated for the intention of improving strength and durability properties of the concrete.

This chapter presents the literature review on the past researches and studies pertaining to lightweight foamed concrete and normal weight concrete with eggshell powder. Eggshell powder has been used as a cementitious material which replaces partial of cement.

The area of concerns for this study focuses on the water absorption and strength properties of LFC incorporated with eggshell powder. It is believed that incorporation of eggshell powder may result in decrease value of water absorption properties and increase value of strength properties, hence enhances its durability.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the materials used, mould preparation, mixing procedures, mix proportions and test methods followed in conducting various experimental investigations. First and foremost, the collection and preparation of materials and moulds are presented in details, followed by presentation of the mix proportions, mixing procedures and test procedures for the lightweight foamed concrete specimens with eggshell as cement replacement material. Two major testing methods namely water absorption and strength properties testing are adopted.

3.2 Raw Materials Used

The mixing compound of lightweight foamed concrete with eggshell powder as cement replacement material, consist of five types of raw materials, namely ordinary Portland cement, eggshell powder, fine aggregate, water and foam.

3.2.1 Ordinary Portland Cement (OPC)

Ordinary Portland cement (OPC) of “ORANG KUAT” branded from YTL Cement Sdn. Bhd. was used throughout the study. The OPC used complied with Type I Portland Cement in accordance with ASTM C150 (2004). The standard requirements and chemical composition details of OPC are given in Table 3.1. The OPC was sieved through 300 μm opening of sieve. The sieved OPC was kept in an airtight container to prevent air moisture contact as hydrated cement particle would affect the formation of calcium silicate hydrate gel.

3.2.2 Eggshell Powder

In this study, the eggshell waste was collected from the business area such as bakeries. The eggshell waste was carefully rinsed and washed to eliminate the organic residue of the egg. Then, the eggshell was dried under the hot sun in order to avoid vermin and bacterial grow. Clean eggshell was collected and ground by blender. The eggshell ground material was sieved by using 63 μm sieve in order to achieve a similar size with cement particle which is 45 μm. This is to make sure a uniform powdery form distributes in eggshell with cement. Table 3.2 shows that calcium oxide (CaO) is the most abundant chemical components in the eggshell.

Table 3.1: Standard Requirements and Chemical Composition Details of OPC (ASTM C150, 2004; SGS analysis report, 2007)

Item		Specification limit (ASTM C150)	OPC (SGS analysis report, 2007)
Silicon dioxide, SiO_2		20.0 min	20.10
Aluminium oxide, Al_2O_3		6.0 max	4.90
Ferric oxide, Fe_2O_3		6.0 max	2.50
Calcium oxide, CaO		A	65.00
Magnesium oxide, MgO		6.0 max	3.10
Sulphur oxide, SO_3		3.0 max	2.30
Ignition loss (LOI)		3.0 max	2.40
Sodium oxide, Na_2O		A	0.20
Potassium oxide, K_2O		A	0.40
Insoluble residue		0.75 max	-
Carbon dioxide, CO_2		A	-
Limestone		5.0 max	-
Calcium carbonate, $CaCO_3$ in limestone		70 min	-
Titanium oxide, TiO_2		-	0.20
Phosphorus oxide, P_2O_2		-	<0.90
Potential	C_3S	A	-
	C_2S	A	-
	C_3A	8 max	-
	C_3AF	A	-
	$C_3AF + 2(C_3A)$	A	-

Note: [A]Not applicable

*All values are in percentage

Table 3.2: Chemical Composition of Eggshell (Freire & Holanda, 2006)

Chemical components	Percentage (%)
CaO	50.7
SiO_2	0.09
Al_2O_3	0.03
MgO	0.01
Fe_2O_3	0.02
Na_2O	0.19
P_2O_5	0.24
SrO	0.13
NiO	0.001
SO_3	0.57
Cl	0.219
Ignition loss	47.8

3.2.3 Fine Aggregate (Sand)

Fine sand is used as the fine aggregate in producing lightweight foamed concrete. This is complies with ASTM C778 (2004), which requires that the graded sand must have 100% passing rate for 600 µm opening. In this study, the sand was dried in an oven at the temperature of 110 °C ± 5 °C for at least 24 hours to remove its uncertain moisture. Sand was sieved through 600 µm opening of sieve after oven dried. The sieving method of sand either by hand or mechanically is described in ASTM C136 (2004).

3.2.4 Water

Water needs to be free from impurities and maintain a neutral pH else the impurities may affect the hydration of cement and its durability. The water for curing purpose is renewed regularly in order to avoid staining on the surface of concrete. According to ASTM C1602 (2006), potable and non-potable water is permitted to be used as mixing water in concrete. Concrete performance requirements for mixing water are compressive strength and time of set. Water was used in three parts of preparing specimen in this study, which were (1) mixing concrete for the production of LFC, (2) curing purpose, (3) agent for absorption testing.

3.2.5 Foam

The foam, an air entraining agent which consists of stable bubbles produced by mixing foaming agent and water in foam generator, was introduced into the plastic mix of mortar in order to produce a material with a cellular structure containing voids between 0.1 and 1 mm for this study. The foam generator was operated under the pressure of 0.5 MPa. The purpose of introducing foam is to control the density of lightweight foamed concrete. The ratio of foaming agent to water is 1:30 by volume. The required density of the foam is 45 ± 5 kg/m^3.

3.3 Mould

Two different types of moulds were used in this study for casting concrete specimens. As such two different types of moulds are required according to the type of test carried out based on the standard and requirement from ASTM and BS. Table 3.3 shows that the type and size of mould used based on respective testing method requirement.

Table 3.3: Type, Size and Number of Mould Required

Testing method	Type of mould	Size (diameter × height)	No of mould prepared
ISAT	Cubic mould	100 mm × 100 mm × 100 mm	3
Water Absorption	Cubic mould	100 mm × 100 mm × 100 mm	3
Sorptivity	Cylindrical mould	100 mm × 200 mm	1
Ultrasonic Pulse Velocity	Cubic mould	100 mm × 100 mm × 100 mm	3
Compressive Strength Test	Cubic mould	100 mm × 100 mm × 100 mm	3

3.4 Mix Proportion

Trial mixes are not required in this study due to the optimal w/c of eggshell based lightweight foamed concrete. The optimal water-to-cement ratio of 0.56 was derived from previous study. All LFC specimens were mixed at this constant w/c ratio.

3.5 Mixing Procedure

The mixing procedure in this study followed the general practices that adopted by normal concrete mixing, all the mixings were carried out manually. OPC, sand, eggshell powder and water were weighted for preparation of raw materials. First, dry mix was performed by manually mixing OPC, sand and eggshell powders in a stainless steel mixing pot until it uniformly mixed. Water was then added into the dry mix. The mix was mixed until the wet mix is uniformly mixed. Flow table spread test was carried out. Next, an amount of foam was weighted and added into the wet mix repeatedly until the desired density of 1300 ± 50 kg/m^3 was achieved. Lastly, fresh lightweight foamed concrete was poured into the mould.

3.6 Curing

Curing condition is very important in gaining the strength of concrete. Curing of concrete specimen shall be commenced as soon as after adequate hardening of the sample under room temperature for a minimum period of 18 – 24 hours. For this study, concrete specimens were cured in a water tank for 7, 28 and 90 days until the testing ages, respectively.

3.7 Fresh Concrete Testing Method

3.7.1 Flow Table Spread Test (ASTM C230, 2004)

This test is to determine the consistency and flow ability of the fresh concrete. This test is carried out before the foam is added, in compliance to the specification in ASTM C230 (2004). In this study, fresh LFC was poured into the conical mould that located at the centre of flat surface as shown in Figure 3.1. Conical mould was then removed following by provided 25 drops to the mortar in a speed of approximately 100 rounds per minute. The number of drops was recorded.

Figure 3.1: Set up of Flow Table Spread Test

3.7.2 Fresh Density Test (ASTM C796, 2004)

In this study, one litre volume of container was tared to zero at weight machine and overfilled with fresh lightweight foamed concrete (LFC). The fresh lightweight foamed concrete was slightly tapped at the sides of the container to allow consolidation of fresh lightweight foamed concrete. The overflow lightweight foamed concrete was struck off and any excessive lightweight foamed concrete found on container surface was wiped off. The one litre container was then weighted to obtain the fresh density of LFC.

3.8 Durability Test

3.8.1 Initial Surface Absorption Test (BS 1881-Part 5, 1970)

Initial surface absorption test (ISAT) is conducted as prescribed as in BS 1881- Part 5 (1970). This test indicates the flow of water onto a dry and flat concrete surface, by the circumstances where the head and temperature are applied constantly. ISAT test is time dependent and comparative to indicate the quality of concrete to resist the absorption of water. It is also an indication of durability of concrete subjected to external chemical attack. Three 100 mm concrete cubes were tested for each lightweight foamed concrete mix in this study.

Prior to testing, the cubes were taken out from water tank and oven dried at a temperature of 105 °C ± 5 °C for 24 hours in order to remove its moisture content. Cooling step was taken by placing the cubes at a room temperature of approximately 28 °C ± 2 °C. Then, cooled oven dried cube was clamped to the test surface so as to ensure an even pressure and good seal around the perimeter. The apparatus was set up based on the schematic diagram as shown in Figure 3.2(a). It is necessary that the water level in the reservoir should be maintained at 200 mm from the top surface of concrete, by mounting capillary tube and reservoir 200 mm ± 5 mm above the cube as shown in Figure 3.3(b). The test was conducted and the measurement was recorded at intervals of 10, 30, 60 and 120 minutes, respectively. Meanwhile, the time in units of seconds for the meniscus to travel 86 divisions was recorded. The data was obtained and the flow can be calculated based on Equation 3.1.

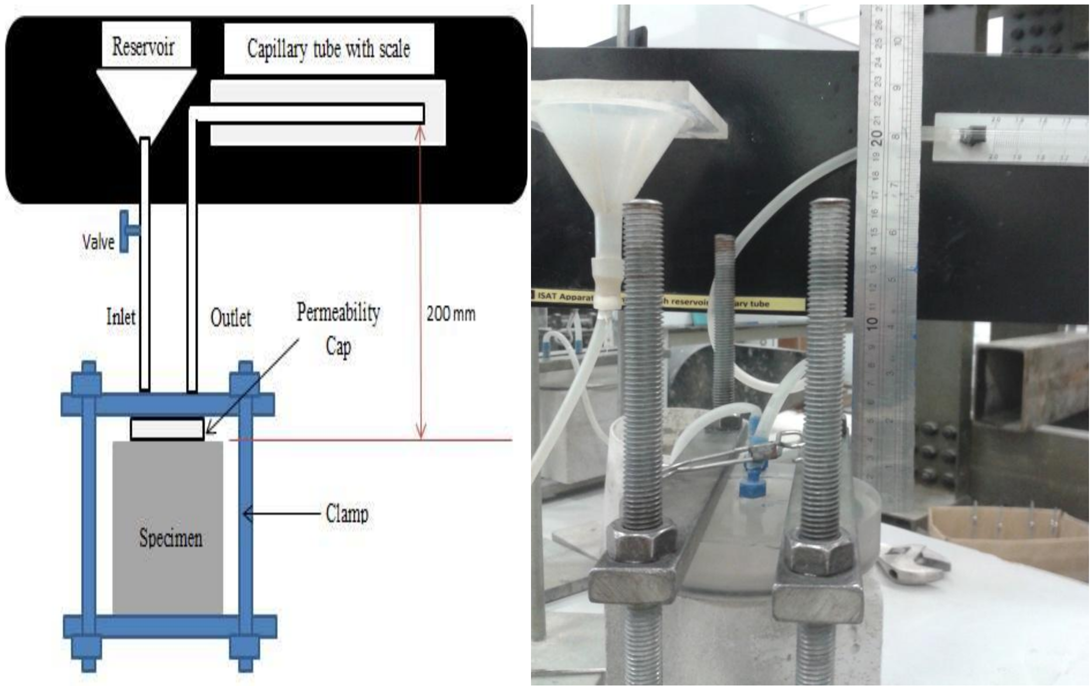
$$f = 60 \times Div \times \frac{0.01}{t} \qquad (3.1)$$

where

f = flow, ml/m^2/s

Div = number of scale division during the period.

t = period, s.



(a) The schematic diagram of ISAT set up.

(b) Water level of reservoir is maintained at 200 mm from the surface of the concrete.

Figure 3.2: The Set Up of Apparatus for Initial Surface Absorption Test (ISAT) as prescribed in BS 1881- Part 5: (a) The schematic diagram and (b) Water level of reservoir is maintained at 200 mm from the surface of the concrete

3.8.2 Sorptivity Test (ASTM C1585, 2004)

The fineness of the capillary pore causes absorption of water into concrete by capillary attraction. Hence, sorptivity is determined by the measurement of the capillary rise absorption rate on LFC specimen. A measure of the absorption rate provides an important indication and assessment on the durability of concrete relative to the porosity of the concrete. Sorptivity test was conducted in accordance with ASTM C1585 (2004). In this study, the specimens (100 mm diameter × 50 mm height) were oven dried for 24 hours and allowed to cool in desiccators for further 24 hours. The diameter and weight of the oven dried specimens were recorded to the nearest 0.01 mm and 0.01 g respectively. During testing, the cast surface which is the bottom of the specimen were immersed in a tray of water at 20 °C to a maximum depth of 1 - 2 mm by resting on steel rods to permit free water movement as shown in Figure 3.3. The uptake of water by capillary absorption wes measured through mass of the specimen at intervals of 5, 10, 15, 30, 60, 90, 120, and 150 minutes from the start of the test. After testing, the bottom surface where in contact with water was wiped off with a paper towel to remove any excess water. The weighing operation was completed within 30 seconds. After weighing, the specimen was returned to the tray immediately and proceeded until the end of the experiment. The average value of sorptivity for three specimens was calculated.

The sorptivity per unit area of the LFC at each time interval was calculated according to the Equation 3.2:

$$I = \frac{m_t}{a/d} \tag{3.2}$$

where

I = sorptivity, mm

m_t = the change in specimen mass at the time, g

a = the exposed area of the specimen, mm^2

d = the density of water, 0.001 g/mm^3.

The sorptivity, I is plotted versus the square root of time ($\sqrt{t}$). The sorptivity coefficient is taken as the slope of I versus $\sqrt{t}$ which might not necessary pass through the origin. The relationship between I and $\sqrt{t}$ can be summarized in the Equation 3.3:

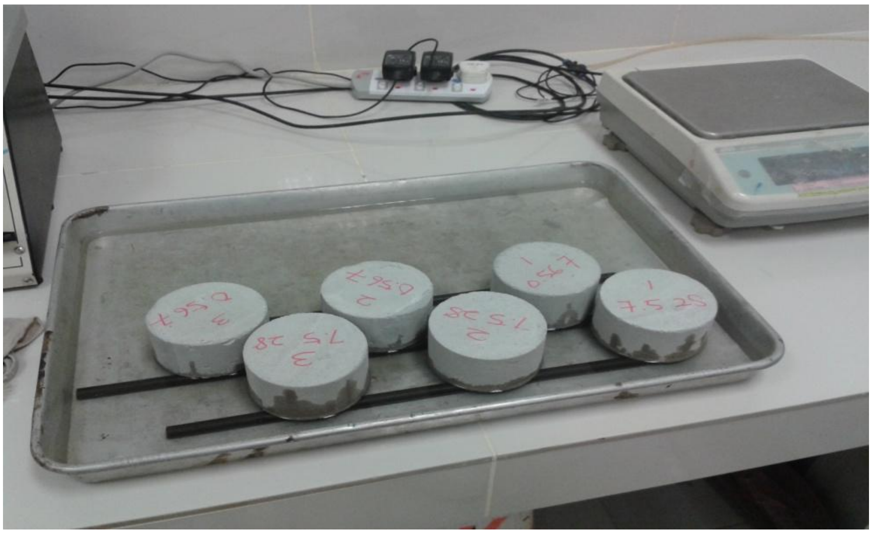
$$I = Sor\sqrt{t} \tag{3.3}$$

where

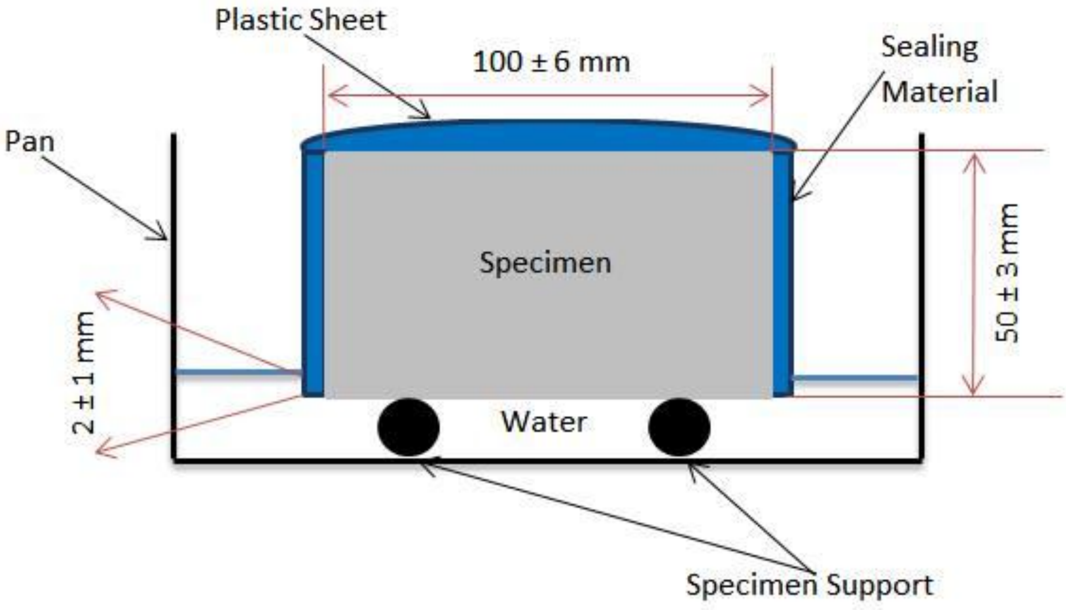
I = sorptivity, mm

Sor = sorptivity coefficient, $mm/s^{0.5}$

$\sqrt{t}$ = square root of time measured in seconds at which the mass is determined, $s^{0.5}$



(a) Specimens were rested on steel rods.



(b) Schematic diagram of sorptivity set up.

Figure 3.3: The Set Up of Apparatus for Sorptivity Test (ASTM C1585, 2004): (a) Specimens were rested on steel rods and (b) Schematic diagram of sorptivity set up

3.8.3 Porosity Test (BS 1881-122)

Porosity test was carried out in this study to calculate the porosity of hardened lightweight foamed concrete in accordance with BS 1881-122. The testing apparatus is designed by applying the concept of Archimedes' principle, which measures the upward buoyant force that is exerted on the concrete specimen immersed in the water. In other words, the weight of the displaced water is equal to the weight of concrete specimen in the water.

Prior to testing, the specimen cubes (100 mm × 100 mm × 100 mm) were taken out one day in advanced from the curing tank. The specimen was wiped to surface dry condition and weighed to obtain the saturated surface dry weight, W_{sat} of the specimen. Next, the apparatus was set up with filling water up to the level of container outlet and letting the water flows. After the water stop flowing out from the container outlet, the specimen was fully immersed into the water. A container was prepared to collect the displaced water. The weight of displaced water indicated the weight of the concrete specimen in the water, which denoted as W_{wat}. The apparatus set up is shown in Figure 3.4. The specimen was oven dried for one day. The oven dried weight of specimen was measured. The porosity of hardened lightweight foamed concrete was calculated by using Equation 3.4.

$$P_r = \frac{W_{sat}-W_{dry}}{W_{sat}-W_{wat}}\ x\ 100\ \% \qquad (3.4)$$

where

P_r = porosity of hardened concrete specimen, %

W_{sat} = saturated surface dry weight of specimen, kg

W_{dry} = oven dried weight of specimen, kg

W_{wat} = weight of specimen in water, kg

Figure 3.4: The Set Up of Apparatus for Porosity and Water Absorption Test as prescribed in BS 1881-122

3.8.4 Water Absorption Test (BS 1881-122)

Water absorption test was carried out in this study to calculate the water absorption capacity of hardened lightweight foamed concrete in accordance with BS 1881-122.

Prior to the testing, the specimen cubes (100 mm × 100 mm × 100 mm) were taken out one day in advanced from the curing tank. The specimen was wiped to surface dry condition and weighed to obtain the saturated surface dry weight, W_{sat} of the specimen. Next, the specimen was oven dried for one day and the oven dried weight of specimen was measured. The water absorption of the hardened lightweight foamed concrete was calculated by using Equation 3.5.

$$W.A. = \frac{W_{sat} - W_{dry}}{W_{dry}} \; x \; 100 \; \% \qquad (3.5)$$

where

W.A. = water absorption of hardened concrete specimen, %

W_{sat} = saturated surface dry weight of specimen, kg

W_{dry} = oven-dried weight of specimen, kg

3.8.5 Ultrasonic Pulse Velocity (ASTM C597, 2004)

Ultrasonic pulse velocity test (UPV) is carried out in accordance with ASTM C597 which covers the determination of the propagation velocity of longitudinal stress wave pulses through concrete. Prior to compressive strength test, UPV of LFC was measured in this study by a Portable Ultrasonic Non-destructive Digital Indicating Tester (PUNDIT 7) that measured the propagation time of ultrasonic waves (54 kHz) through a cubic specimen (100 mm × 100 mm × 100 mm) with accuracy up to 0.1 μs. Direct transmission was adopted by positioning the transmitter and receiver on the middle of each opposing surface of the specimen in accordance with BS EN 12504-4 as shown in Figure 3.5(a). This is the arrangement which gives most reliable results as the signal strength is the highest. Prior to testing, the apparatus was set up and calibrated to 25.2 μs as shown in Figure 3.5(b). Knowing the length of path travelled through the concrete, the pulse velocity can be calculated by using Equation 3.6.

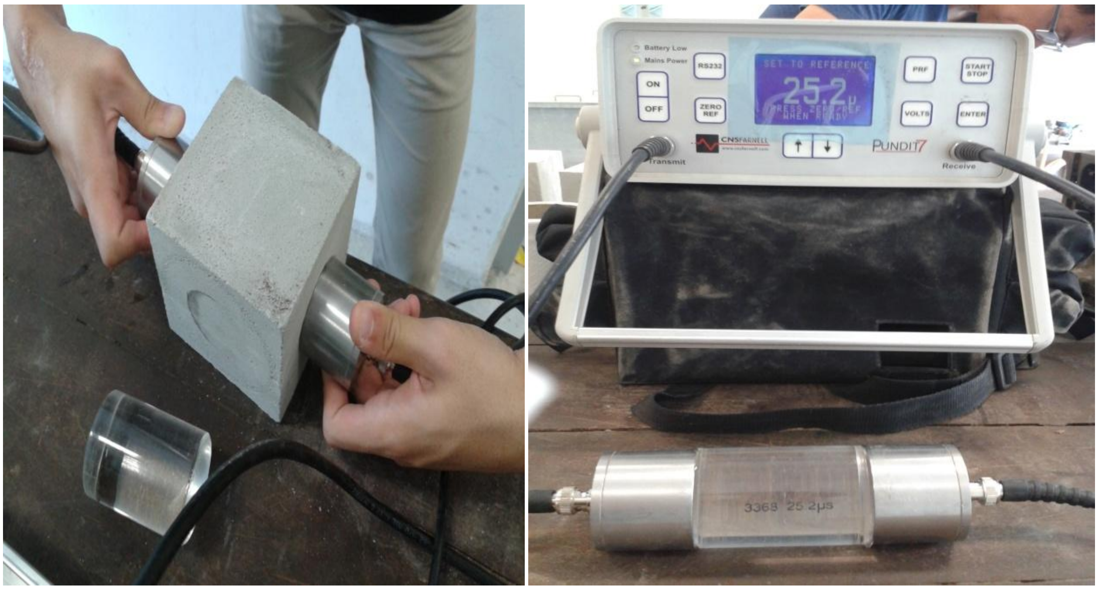
$$V = \frac{x}{t_{us}} \quad (3.6)$$

where

V = pulse velocity, km/s

x = length of path travelled, mm

t_{us} = transit time, μs



(a) Direct transmission method adopted in UPV test.
(b) Calibration of equipment prior to testing.

Figure 3.5: The Apparatus Set Up of Ultrasonic Pulse Velocity test (UPV) in accordance with ASTM C597: (a) Direct transmission method and (b) Calibration of equipment

3.9 Destructive Hardened Concrete Test

There is only one destructive hardened concrete test method carried out in this study. The destructive hardened concrete test was carried out at the final stage of the study among all the testing methods.

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

The compressive strength test was conducted in this study by using INSTRON 5582 Testing Machine in accordance with BS EN 12390-3 (2002). Constant axial loading rate of 0.02 mm/s was applied on the hardened cubic concrete specimen.. Three cubic specimens with dimension of 100 mm × 100 mm × 100 mm were tested and average values were obtained for each batch of mix.

The cubic specimens were oven-dried for 24 hours before the commencement of the testing. The dimension of the specimen was measured by using digital vernier calliper to determine the cross-sectional area before the testing. Then, the test specimen was located at the centre of the testing machine platform as shown in Figure 3.6. The test was then started at the specified loading rate until the test specimen failed and cracks appeared on the specimen's surface. The maximum load of the test specimen was recorded in order to calculate the compressive strength. Compressive strength of the test specimen was calculated by using Equation 3.7.

$$f_c = \frac{P}{A} \tag{3.7}$$

where

f_c = compressive strength, MPa

P = maximum load sustained by specimen, N

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

Figure 3.6: The Set Up of Apparatus for the Compressive Strength Test

3.10 Consistency and Stability

Consistency and stability of the concrete mix can be determined by obtaining and calculating the fresh and hardened concrete densities. The mix is said to be stable if the ratio of between fresh density and hardened density is nearly to unity. Nevertheless, the mix is consistent if the ratio between fresh density and designated density is nearly to unity. The consistency of the LFC mix was calculated by Equation 3.8 while the stability of the mix was calculated by Equation 3.9.

$$Consistency = \frac{Fresh\ Density}{Designated\ Density} \tag{3.8}$$

$$Stability = \frac{Fresh\ Density}{Hardened\ Density} \tag{3.9}$$

3.11 Performance Index

Performance index was calculated in this study in order to obtain more accurate result by considering the density of the specimen. The density of the specimen was fluctuated among others although the density obtained is within 1300 kg/m^3 with tolerance ± 50 kg/m^3. Thus, performance indexes of LFCs were calculated by using Equation 3.10.

$$PI = \frac{f}{hardened\ density/1000} \tag{3.10}$$

where

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

f_c = compressive strength, MPa

3.12 Summary

Lightweight foamed concrete with density of 1300 kg/m^3 incorporated with eggshell powder as 2.5 % and 5.0 % of cement replacement material were produced by the pre-foaming method. Three mix proportions were prepared in this study; namely LFC-ES0, LFC-ES2.5 and LFC-ES5.0. A total of three 100 mm cubes and a 100 mm × 200 mm cylinder were produced for each batch of mix proportion. The specimens were cured under water curing condition for 7, 28 and 90 days followed by the properties testing namely ISAT, sorptivity, water absorption, porosity, ultrasonic pulse velocity and compressive strength tests.

CHAPTER 4

INITIAL SURFACE ABSORPTION, SORPTIVITY, WATER ABSORPTION AND POROSITY

4.1 Introduction

This chapter discusses the main results of water absorption properties that carried out on lightweight foamed concrete, namely LFC-CTR, LFC-ES2.5 and LFC-ES5.0. All the specimens were water cured for 7, 28 and 90 days of ages before testing. All the specimens results were presented on the basis of dividing its own density in order to obtain more accurate and consistent results for this study. The effects of eggshell powder as cement replacement material on its durability properties in terms of initial surface absorption, sorptivity, porosity and water absorption, either their relationship, are discussed in this chapter.

4.2 Mix Proportions

Table 4.1 presents the mix proportions used in this study for LFC-CTR, LFC-ES2.5 and LFC-ES5.0.

Table 4.1: Mix Proportions

Specimen	w/c[5]	Material (kg/m³)					Flow Table Spread Test (drops)	Consistency	Stability
		Cement	Eggshell	Sand	Water	Foam			
LFC-CTR[1]-0.56[4]	0.56	500	0	500	280	16 - 20	13	1.026	0.959
LFC-ES2.5[2]-0.56	0.56	487.5	12.5	500	280	16 - 20	15	1.003	0.961
LFC-ES5.0[3]-0.56	0.56	475	25	500	280	16 - 20	14	1.030	0.967

Note:

[1]LFC-CTR = lightweight foamed concrete with 0 % of eggshell powder as partial cement replacement material

[2]LFC-ES2.5 = lightweight foamed concrete with 2.5% of eggshell powder as partial cement replacement material

[3]LFC-ES5.0 = lightweight foamed concrete with 5.0 % of eggshell powder as partial cement replacement material

[4]0.56 is the optimal water to cement ratio

[5]w/c = water to cement ratio

LFC-CTR, LFC-ES2.5 and LFC-ES5.0 have nearly constant drops with each other. However, LFC-ES2.5 and LFC-ES5.0 have more drops than LFC-CTR which may due to the eggshell fineness enhances the water absorption. The values of consistency and stability for LFC-CTR, LFC-ES2.5 and LFC-ES5.0 are nearly to unity as shown in Table 4.1. This means that the foam in LFCs were maintained its stability and firmness well.

4.3 Initial Surface Absorption Test (ISAT)

The ISAT results for LFC-CTR, LFC-ES2.5 and LFC-ES5.0 at 90 days of curing ages are illustrated in Figure 4.1.

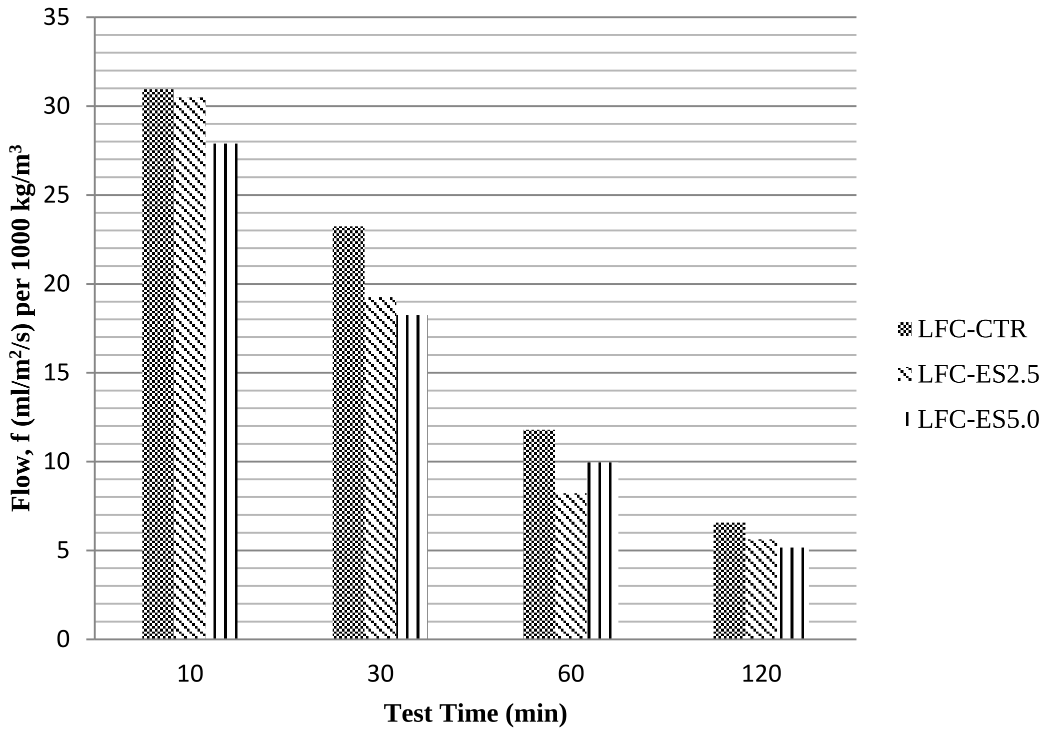


Figure 4.1: Effect of Incorporation of Eggshell Powder in 90-day LFC on its Initial Surface Absorption through Testing Time of 10, 30, 60 and 120 minutes

Figure 4.1 shows that the incorporation of eggshell powder has resulted a decreased flow or initial surface absorption as compared to control mix. This is due to the reduction in the capillary pores of LFC with the formations of C-S-H gel by the hydration process that gradually filled the original water filled space. Eggshell which contains abundant calcium carbonate is able to perform its cementitious properties. Another possible reason is that the capillary pores were interrupted and segmented by the eggshell particles at which the passage is only partly connected. Table 4.2 shows the initial surface absorption of LFC-ES2.5 and LFC-ES5.0 was 14 % and 7 % lower than that of LFC-CTR respectively. Incorporation of eggshell powder has given lower initial surface absorption than that of control LFC. In other words, the permeability of LFC incorporated with eggshell is lower than that of LFC-CTR.

Table 4.2: Effect of Incorporation of Eggshell in 90-day LFC on its 120 minutes ISAT

Age	Type of Specimen	Percentage of ISAT corresponded to that of 90-day control mix
90	LFC-CTR	100
	LFC-ES2.5	86
	LFC-ES5.0	79

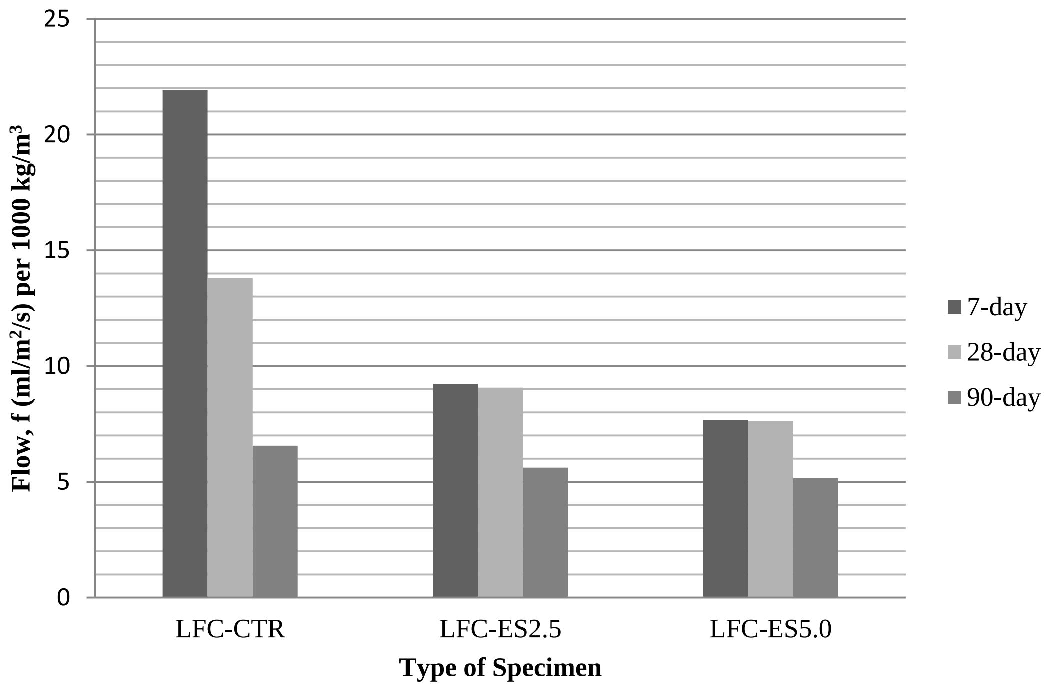


Figure 4.2: Effect of Incorporation of Eggshell Powder in LFC on its 120 minutes Initial Surface Absorption for 7, 28 and 90 Days of Curing Periods

Figure 4.2 summarizes the effect of incorporation of eggshell powder in LFC on its initial surface absorption at 7, 28 and 90 days of ages. Furthermore, the effect of curing period on its initial surface absorption for various types of specimens is illustrated in Figure 4.2. The flow for LFC-CTR, LFC-ES2.5 and LFC-ES5.0 were decreased with the curing period which is illustrated in Table 4.3. The flow for LFC-ES2.5 and LFC-ES5.0 at 7-day were 9.23 ml/m^2/s and 7.68 ml/m^2/s respectively; while the flow for LFC-ES2.5 and LFC-ES5.0 at 28-day were 9.07 ml/m^2/s and 7.63 ml/m^2/s respectively. The effect of curing period at 7-day and 28-day was not significantly deviated between LFC-ES2.5 and LFC-ES5.0. The incorporation of eggshell in LFC shows slightly effect at curing periods of 7-day and 28-day. In spite of that, the incorporation of eggshell in LFC shows significantly effect at 90 days of curing period which resulted in lower initial surface absorption or flow. Therefore, the eggshell in LFC has showed its later effect on its initial surface absorption at curing period of 90-day.

Table 4.3: Effect of Curing Period on Initial Surface Absorption for Various Types of Specimens at Testing Time of 120 minutes

Type of Specimen	Flow, f (ml/m^2/s) per 1000 kg/m^3		
	7-Day	**28-Day**	**90-Day**
LFC-CTR	21.92	13.80	6.56
LFC-ES2.5	9.23	9.07	5.62
LFC-ES5.0	7.68	7.63	5.16

4.4 Sorptivity

Sorptivity is the ability of water movement in pores through the concrete by capillary suction when exposed to ambient medium. The effect of incorporation of eggshell in LFC on its sorptivity at 90 days of curing periods is illustrated in Figure 4.3.

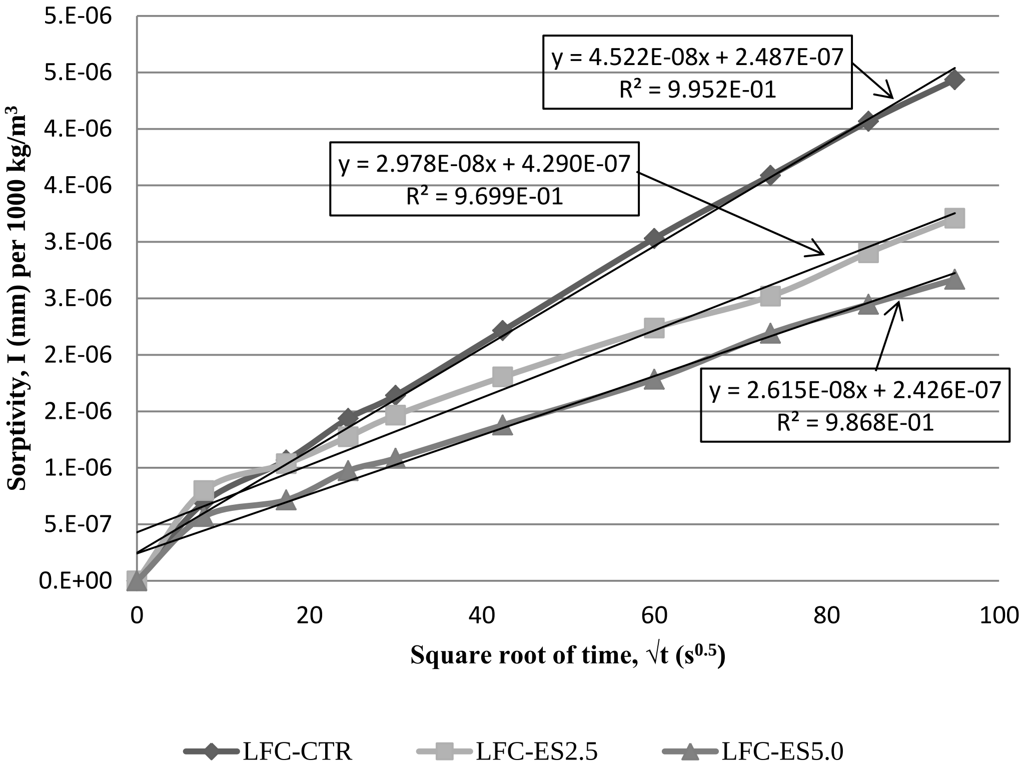


Figure 4.3: Effect of Incorporation of Eggshell Powder in LFC on its Sorptivity at 90 Days of Curing Periods

The initial absorptions of all specimens were increased sharply between 0 $s^{0.5}$ and 7.75 $s^{0.5}$ while the secondary absorptions of all specimens were increased gradually after 7.75 $s^{0.5}$ which are illustrated in Figure 4.3. LFC-ES5.0 has shown the lowest slope among the other specimens. The slope that defined as sorptivity coefficient of LFC-ES2.5 and LFC-ES5.0 were lower than that of LFC-CTR as shown in Table 4.4. The sorptivity coefficient of LFC-ES2.5 was 34 % lower than that of LFC-CTR while the sorptivity coefficient of LFC-ES5.0 was 42 % and 8% lower than that of LFC-CTR and LFC-ES2.5 respectively. In other words, the incorporation of eggshell in LFC has resulted decreased sorptivity as compared to that of control mix. The connected pores of LFC-ES2.5 and LFC-ES5.0 were lesser than that of LFC-CTR. The sorptivity of all specimens were directly proportional to the square root of time which gave R^2 value nearly to unity as shown in Table 4.4. A similar study by Hall (1989) explained that the water movement was based on the unsaturated flow theory (Ramamurthy *et al.*, 2009).

Table 4.4: Effect of Incorporation of Eggshell in LFC on its Sorptivity at 90 Days of Curing Periods

Age	Type of Specimen	Sorptivity Coefficient, Sor ($\times 10^{-8}$ $mm/s^{0.5}$)	Linear Equation ($\times 10^{-8}$)	R^2	Percentage of Sorptivity corresponded to that of control mix at 90 days of age
90	LFC-CTR	4.522	y = 4.522x + 0.249	0.995	100
	LFC-ES2.5	2.978	y = 2.978x + 0.429	0.970	66
	LFC-ES5.0	2.615	y = 2.615x + 0.243	0.986	58

4.5 Water Absorption

The water absorption of LFCs at 90 days of curing periods is illustrated in Figure 4.4.

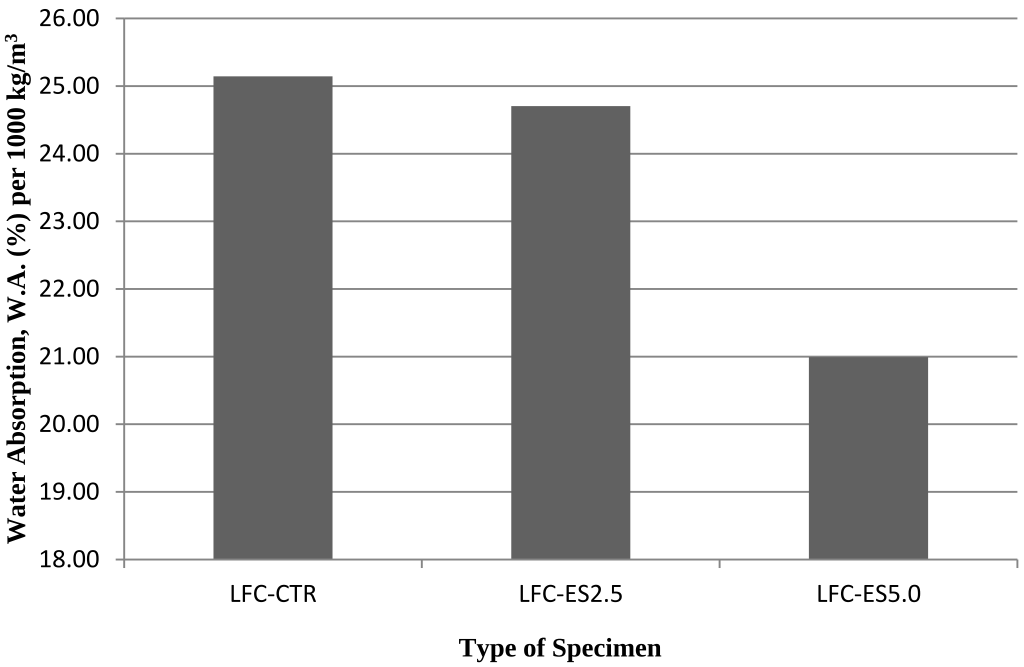


Figure 4.4: Effect of Incorporation of Eggshell in 90-Day LFC on its Water Absorption

The water absorption per unit density (1000 kg/m^3) for LFC-CTR, LFC-ES2.5 and LFC-ES5.0 were 25.14 %, 24.70 % and 20.99 % respectively as shown in Figure 4.4. The effect of incorporation of eggshell has decreased its water absorption as compared to that of control mix. However, the water absorption of LFC-ES2.5 was slightly 2 % lower than LFC-CTR while the water absorption of LFC-ES5.0 was 17 % lower than LFC-CTR as shown in Table 4.5. The incorporation of 5.0 % eggshell as partial cement replacement material has notable effect on its water absorption. A similar study on normal weight concrete by Ramamurthy *et al.* (2009) opined that the water absorption is mainly influenced by paste phase. The C-S-H gel formation has reduced the pore size which resulted in lower water absorption in LFC-ES5.0.

Table 4.5: Effect of Incorporation of Eggshell in 90-Day LFC on its Water Absorption

Age	Type of Specimen	Percentage of Water Absorption corresponded to that of control mix at 90 days of age
90	LFC-CTR	100
	LFC-ES2.5	98
	LFC-ES5.0	83

4.6 Porosity

The porosity of LFCs at 90 days of curing periods is illustrated in Figure 4.5.

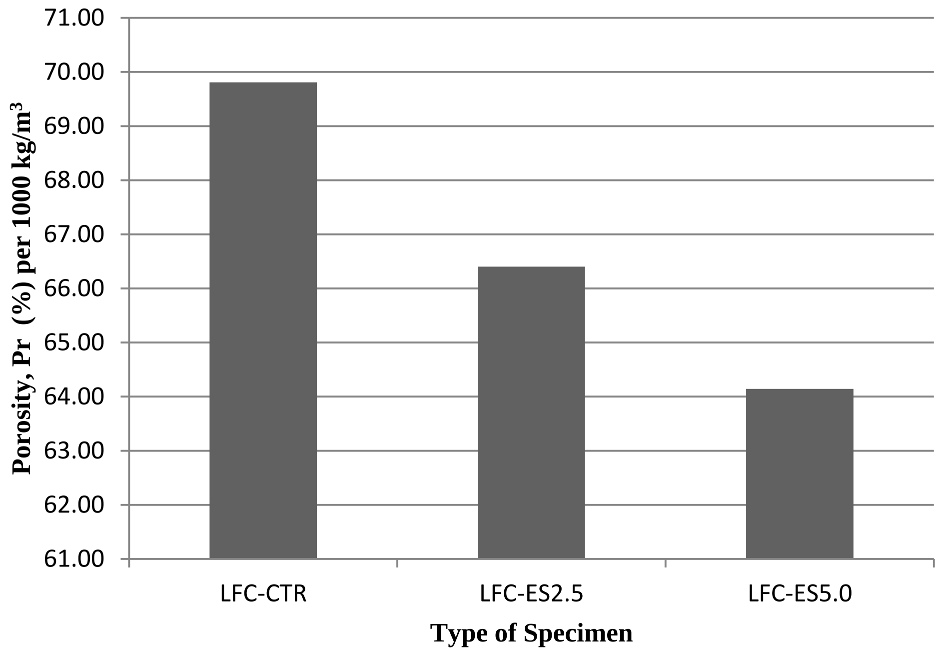


Figure 4.5: Effect of Incorporation of Eggshell in 90-Day LFC on its Porosity

The porosity per unit density (1000 kg/m^3) for LFC-CTR, LFC-ES2.5 and LFC-ES5.0 were 69.81 %, 66.40 % and 64.14 % respectively as shown in Figure 4.5. The effect of incorporation of eggshell has decreased its porosity as compared to that of control mix. The porosity of LFC-ES2.5 and LFC-ES5.0 were 5 % and 8% lower than LFC-CTR respectively as shown in Table 4.6. Eggshell is a porous material which responsible for exchange of water (Dennis *et al.* 1996). Despite of that, the eggshell particles shows its dominant cementitious effect on LFC instead of its porous structure. Therefore, the average pore size has been reduced by the cementitious effect of eggshell which resulted in lower porosity. Matschei (2006) stated that calcite (form of calcium carbonate) does influence both porosity and permeability. Thus, the incorporation of eggshell in LFC has decreased its porosity. A similar result obtained by Yerramala (2014) found that the incorporation of eggshell in normal weight concrete has shown lower porosity as compared to that of control mix.

Table 4.6: Effect of Incorporation of Eggshell in 90-Day LFC on its Porosity

Age	Type of Specimen	Percentage of Porosity corresponded to that of control mix at 90 days of age
90	LFC-CTR	100
	LFC-ES2.5	95
	LFC-ES5.0	92

4.7 Summary

Eggshell powder in lightweight foamed concrete as partial cement replacement material plays significant role in enhancing its durability properties in terms of initial surface absorption, sorptivity, water absorption as well as porosity.

Both LFC-ES2.5 and LFC-5.0 have lower initial surface absorption as compared to that of control mix. LFC-ES5.0 has obtained the lowest initial surface absorption for test time of 120 minutes at 90 days of age which gave a flow of 5.16 ml/m^2/s per 1000 kg/m^3 as compared to that of LFC-CTR. This is due to the eggshell particles has perform its cementitious behaviour in LFC. Another possible reason is that the capillary pores were interrupted and segmented by the calcium carbonate particles at which the passage is only partly connected. Low initial surface absorption indicates a better durability and poor water absorption properties of LFC. In addition, the initial surface absorptions of LFCs were decreasing with curing period due to the capillary pore filled up by the C-S-H gel.

Both LFC-ES2.5 and LFC-5.0 have lower sorptivity as compared to that of control mix. LFC-ES5.0 has obtained the lowest sorptivity for test time of 120 minutes at 90 days of age which gave a sorptivity coefficient of 2.615×10^{-8} $mm/s^{0.5}$ as compared to that of LFC-CTR. The connected pores of both LFC-ES2.5 and LFC-ES5.0 were lesser than that of LFC-CTR. The capillary suction of LFC-ES2.5 and LFC-ES5.0 were lower than that of LFC-CTR. The C-S-H gel has filled up the pores and segmented its interconnectivity. Besides, the porous irregular shape of eggshell particles has interrupted and segmented the capillary pores inside LFC which decreases the ingress of water inside LFC.

Both LFC-ES2.5 and LFC-5.0 have lower water absorption and porosity as compared to that of control mix. LFC-ES5.0 has obtained lowest water absorption and porosity at 90 days of age which were 20.99 % and 64.14 % respectively as compared to that of LFC-CTR. This is due to the water absorption is mainly influenced by paste phase. The C-S-H gel formation has reduced the pore size which resulted in lower water absorption and porosity.

Incorporation of eggshell in LFC has resulted in lower initial surface absorption, sorptivity, water absorption and porosity, by which it indicates a better durability and lower water absorption properties.

CHAPTER 5

COMPRESSIVE STRENGTH AND ULTRASONIC PULSE VELOCITY (UPV)

5.1 Introduction

This chapter discusses about the secondary results of strength properties that carried out on lightweight foamed concrete, namely LFC-CTR, LFC-ES2.5 and LFC-ES5.0. All the specimens were water cured for 7, 28 and 90 days of ages prior to testing. All the specimens results were presented on the basis of dividing its own density in order to obtain more accurate and consistent results for this study. The effects of eggshell powder as cement replacement material on its strength properties in terms of compressive strength and ultrasonic pulse velocity are discussed in this chapter.

5.2 Performance Index of Compressive Strength

Performance index is a parameter that used to obtain the strength of concrete per 1000 kg/m^3. In practices, it is impossible to produce every specimen with same density. Therefore, performance index has been adopted in order to obtain more accurate and reliable results. The performance indexes of compressive strength for LFC-CTR, LFC-ES2.5 and LFC-ES5.0 are illustrated in Figure 5.1.

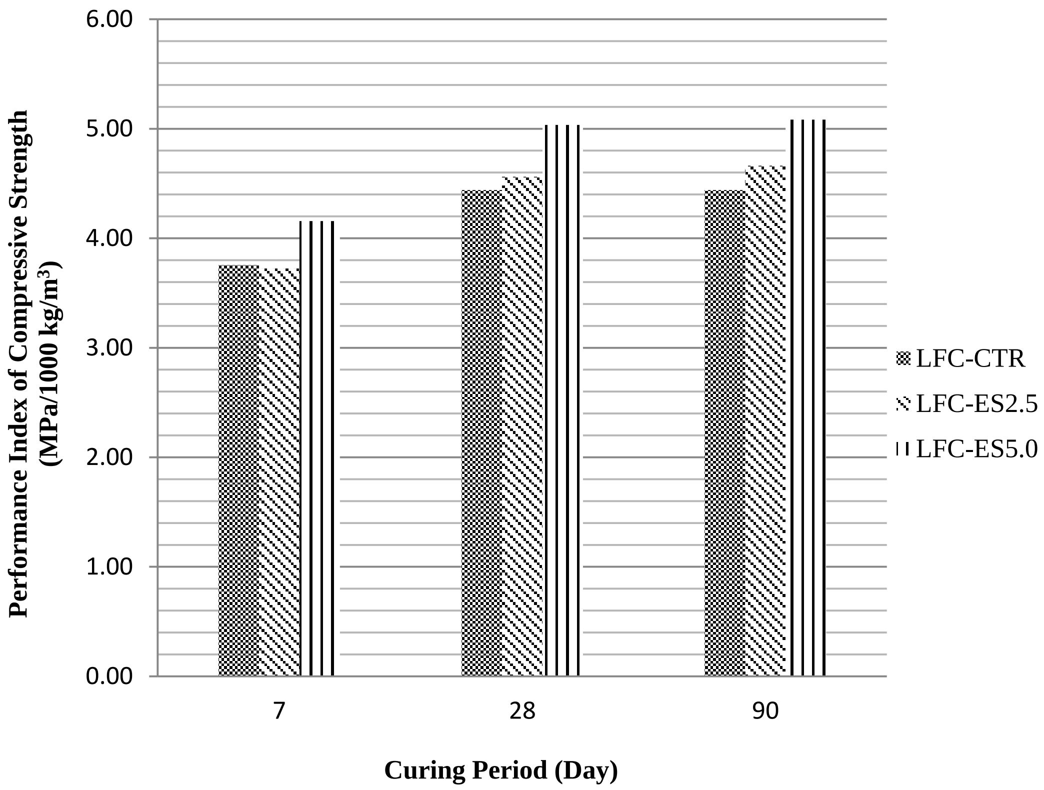


Figure 5.1: Performance Indexes of Compressive Strength at 7, 28 and 90 Days of Curing Periods for LFC-CTR, LFC-ES2.5 and LFC-ES5.0

Figure 5.1 shows the performance index of compressive strength for LFC-CTR, LFC-ES2.5 and LFC-ES5.0 at 7, 28 and 90 days of curing periods. Generally, it is clearly shown that the performance indexes of compressive strength for LFC-CTR, LFC-ES2.5 and LFC-ES5.0 were increased throughout the curing periods. Both LFC-ES2.5 and LFC-5.0 have higher performance indexes than that of LFC-CTR at 28 and 90 days of curing periods. LFC-ES5.0 has higher performance index than that of LFC-CTR while LFC-ES2.5 has almost same performance index with LFC-CTR at 7 days of curing period. The highest performance index of compressive strength achieved by LFC-CTR, LFC-ES2.5 and LFC-ES5.0 are 4.44 MPa per 1000 kg/m^3, 4.66 MPa per 1000 kg/m^3 and 5.08 MPa per 1000 kg/m^3 respectively at 90 days of curing period as shown in Table 5.1. In addition, LFC-ES5.0 shows the highest performance indexes of compressive strength than that of LFC-CTR for all the curing periods.

A similar study was deduced that 5 % eggshell as partial cement replacement in normal weight concrete has possessed highest compressive strength as compared to that of control mix (Yerramala, 2014). Yerramala (2014) suggested that the eggshell has same behaviour as lime stone filler in strength properties. Eggshell is mostly made up of calcium carbonate which possesses cementitious properties. The addition of calcium carbonate can act as inert filler within the concrete which helps to increase compressive strength of concrete (Matschei *et al.*, 2006). Another possible reason is that the calcium carbonate reacts with alumina phases of cement and produces monocarboaluminates which resulted increment of the strength (Ramezanianpour & Hooton, 2014).

Table 5.1: Performance Indexes for Lightweight Foamed Concrete at 7, 28 and 90 Days of Curing Periods

Age	Type of Specimen	Performance Index
7-Day	LFC-CTR	3.75
	LFC-ES2.5	3.72
	LFC-ES5.0	4.16
28-Day	LFC-CTR	4.44
	LFC-ES2.5	4.56
	LFC-ES5.0	5.03
90-Day	LFC-CTR	4.44
	LFC-ES2.5	4.66
	LFC-ES5.0	5.08

5.3 Correlation between Compressive Strength and Ultrasonic Pulse Velocity (UPV)

It is well known that the UPV can be correlated to compressive strength. The effect of incorporation of eggshell on compressive strength and ultrasonic pulse velocity for LFC-CTR, LFC-ES2.5 and LFC-ES5.0 at different curing periods are illustrated in Figure 5.2.

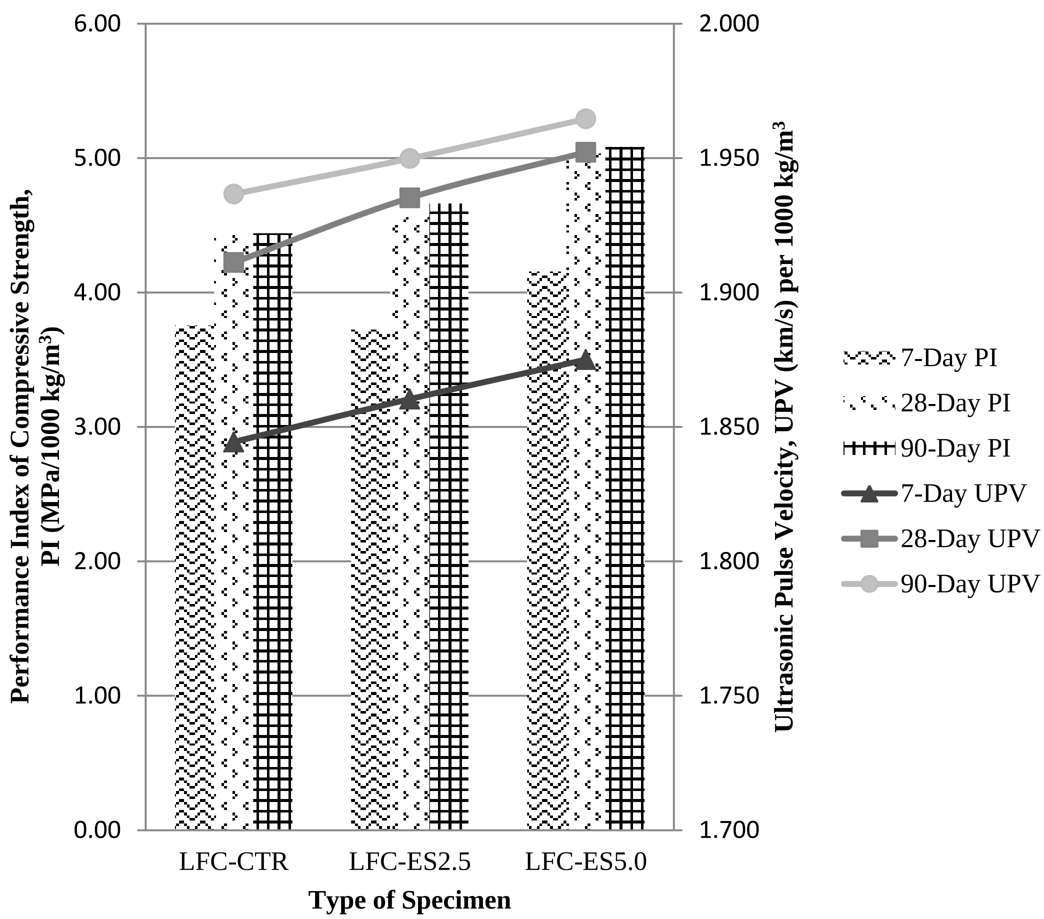


Figure 5.2: Effect of Incorporation of Eggshell in LFC on its Performance Index of Compressive Strength and Ultrasonic Pulse Velocity at 7, 28 and 90 Days of Curing Periods

Generally, both compressive strength and UPV for LFC-CTR, LFC-ES2.5 and LFC-ES5.0 have increased throughout the curing periods. It was clearly shown that 90-Day UPV has higher values than 28-Day UPV and 7-Day UPV as illustrated in Figure 5.2. The effect of incorporation of eggshell has higher UPV than that of control mix for all the curing periods. In other words, UPV is directly proportional to the percentage of eggshell as partial cement replacement. It can be observed that LFC-ES5.0 has possessed the highest compressive strength and UPV among all specimens as illustrated in Figure 5.2. This is due to reduced porosity and pore size in LFC-ES5.0 which resulted in higher pulse velocity. A general statement can be accepted that the ultrasonic pulse wave is travelling through solid medium than porous medium. Therefore, it can be deduced that the porous microstructure of LFC-

ES5.0 was lesser than LFC-CTR and LFC-ES2.5 which resulted in higher UPV value as well as compressive strength. As discussed earlier, the reduced porous structure of LFC-ES5.0 may due to the effect of eggshell derived as calcium carbonate which acts as inert filler.

A recent study has opined that the effect of inclusion of lime as partial cement replacement has shown the increment of both compressive strength and UPV (Acharya & Patro, 2015).

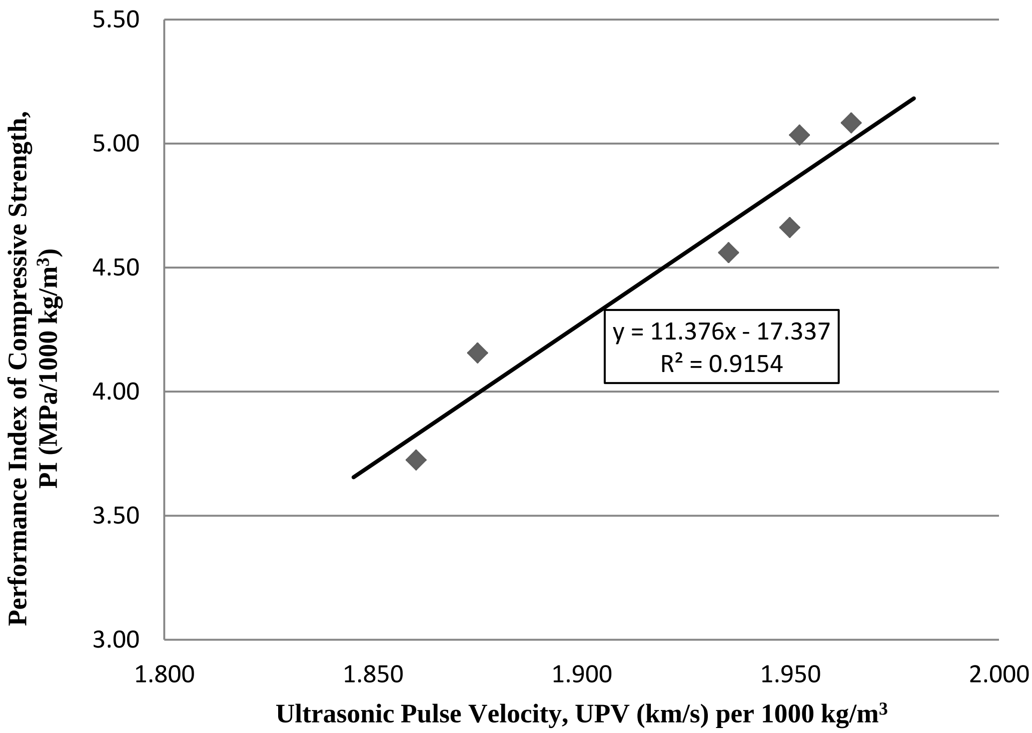


Figure 5.3: Correlation between Performance Index of Compressive Strength and Ultrasonic Pulse Velocity for LFC incorporated with 2.5 % – 5.0 % Eggshell Powder as Partial Cement Replacement Material up to 90 Days of Curing Periods

Figure 5.3 shows the effect of incorporation of eggshell on its correlation between performance index of compressive strength and UPV at different curing periods. The data were plotted at three respective curing periods. The performance index of compressive strength is said directly proportional to UPV which gave a R^2

value of 0.915 that nearly to unity as illustrated in Figure 5.3. A similar study by Gül *et al.* (2006) shown that both UPV and compressive strength were low at early stages but increased with the curing periods and thus their relationship were correlated. In this study, the performance index of compressive strength was increased with UPV for LFC incorporated with 2.5 % - 5.0 % eggshell powder as partial cement replacement up to 90 days of curing periods.

5.4 Strength-Porosity Relationship

The relationship between performance index of compressive strength and porosity per unit density (1000 kg/m^3) for LFC incorporated with 2.5 % - 5.0 % eggshell powder as partial cement replacement up to 90 days of curing periods is illustrated in Figure 5.4.

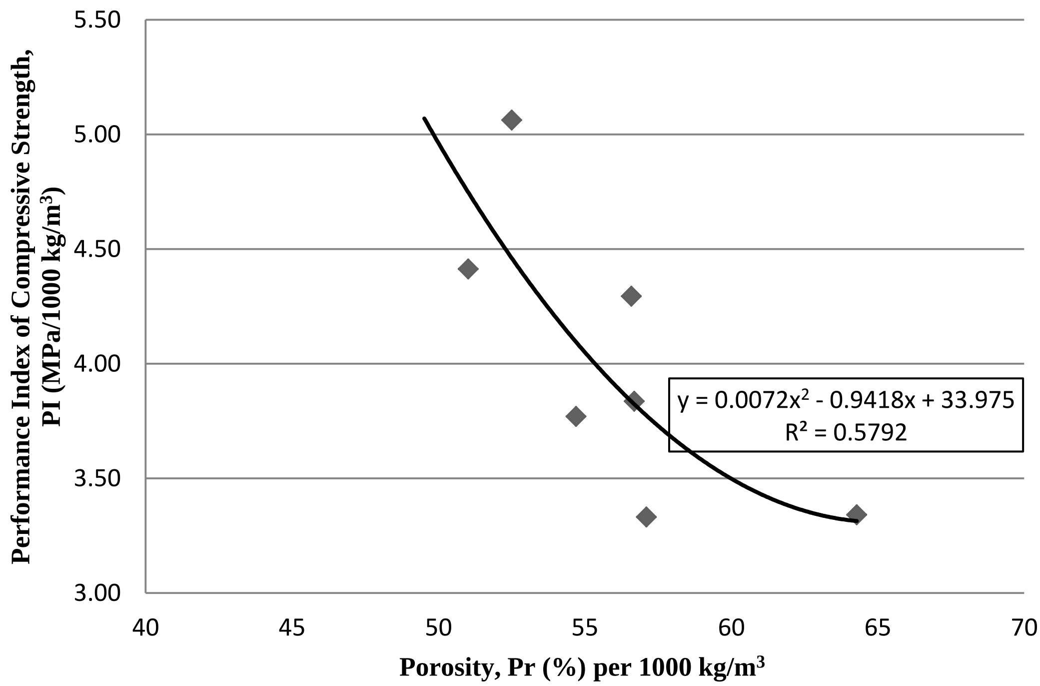


Figure 5.4: Strength-Porosity Relationship for LFC incorporated with 2.5 % – 5.0 % Eggshell Powder as Partial Cement Replacement Material up to 90 Days of Curing Periods

Basically, there exists a fundamental inverse relationship between porosity and compressive strength of concrete. In this study, the performance index of compressive strength was basically decreased with porosity at decreasing rate which gave a R^2 value of 0.579 as illustrated in Figure 5.4. Previous study has opined that calcium carbonate has the ability to enhance the strength by reducing its porosity which was discussed in the section earlier (Ramezanianpour & Hooton, 2014). It can be deduced that the performance index of compressive strength is inversely proportional to its porosity in this study.

5.5 Summary

Other than durability and water absorption properties, lightweight foamed concrete incorporated with eggshell shows its enhancement on strength properties in terms of compressive strength and ultrasonic pulse velocity (UPV).

In a nutshell, LFC-ES5.0 has achieved the highest performance index of compressive strength as well as ultrasonic pulse velocity for all the curing periods. This is due to the calcium carbonate that derived from eggshell has reacted with alumina phases of cement which resulted in higher compressive strength. Furthermore, calcium carbonate that acted as inert filler has helped to increase the strength.

The performance index of compressive strength is directly proportional to UPV for LFC incorporated with 2.5 % - 5.0 % eggshell powder as partial cement replacement. Basically, performance index of compressive strength is inversely proportional to porosity as the calcium carbonate reacts with cement which resulted in lesser porous microstructure.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

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

The first objective of this study is to produce and achieve the density of 1300 ± 50 kg/m^3 for all lightweight foamed concrete specimens at w/c of 0.56. This was achieved as the densities of three types of lightweight foamed concrete prepared namely LFC-CTR, LFC-ES2.5 and LFC-ES5.0 were in the range of the desired density as shown in Table B1.

The second objective is to study the effect of eggshell as partial cement replacement material on durability properties of lightweight foamed concrete in terms of initial surface absorption, sorptivity, water absorption, porosity, ultrasonic pulse velocity and compressive strength. Incorporation of eggshell into lightweight foamed concrete has decreased its initial surface absorption, sorptivity, water absorption and porosity as compared to those of the control mix. Lightweight foamed concrete incorporated with eggshell has lower water absorption properties which resulted in better durability as compared to that of control mix.

The third objective is to establish the relationship between compressive strength-ultrasonic pulse velocity and compressive strength-porosity of lightweight foamed concrete incorporated with eggshell powder as partial cement replacement material. Correlation between compressive strength and UPV was developed which it shows that the compressive strength is directly proportional to UPV for LFC incorporated with 2.5 % - 5.0 % eggshell powder as partial cement replacement material. In this study, the performance index of compressive strength is inversely proportional to its porosity for LFC incorporated with 2.5 % - 5.0 % eggshell powder as partial cement replacement material.

6.2 Recommendations

The study of lightweight foamed concrete incorporated with eggshell as cement replacement material is innovative and sustainable product among construction and building materials. In order to discover and improve this research work in future, there are few aspects are suggested for further improvement:

1. Increase the percentage of eggshell as partial cement replacement material to further study the development of water absorption and strength properties of lightweight foamed concrete in order to achieve its optimal condition.
2. Adopt different curing methods for the concrete specimens and study the impact on other engineering properties such as thermal conductivity, sound insulation etc.
3. Produce and study its properties on lightweight foamed concrete incorporated with not only eggshell but also other cementitious or pozzolanic materials as partial cement replacement materials.

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APPENDICES

APPENDIX A: Consumption of Livestock Products in Malaysia, 2005 – 2014 (DVS, 2014)

MALAYSIA : PENGGUNAAN HASILAN TERNAKAN, 2005-2014

Malaysia : Consumption of Livestock Products, 2005-2014

KOMODITI *Commodity*	WILAYAH *Region*	2005	2006	2007	2008	2009	2010	2011	2012	2013[P]	2014[E]
DAGING LEMBU/KERBAU	S. Malaysia	127,956	135,219	134,568	126,677	141,666	145,412	158,111	168,192	184,202	190,201
Beef	Sabah	7,544	4,604	5,867	4,736	2,471	4,885	5,039	7,700	10,334	11,729
(M. Tan/M. Ton)	Sarawak	3,480	6,550	4,297	4,116	5,119	4,105	4,239	5,587	7,020	8,236
Jumlah	*Total*	138,980	146,373	144,732	135,529	149,256	154,402	167,388	181,479	201,556	210,166
DAGING KAMBING/BEBIRI	S. Malaysia	16,336.0	17,129.0	16,731.7	17,961.6	18,408.2	19,054.0	19,042.03	23,239.15	27,298.69	33,390.01
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	637.0	671.0	766.5	1,051.4	901.3	1,022.7	1,136.78	1,145.4	1,468.99	1,545.60
Jumlah	*Total*	16,973.0	17,800.0	17,498.2	19,013.0	19,309.4	20,076.7	20,178.8	24,384.6	28,767.7	34,935.60
DAGING BABI	S. Malaysia	180,505	176,813	160,957	159,194	172,186	202,681	180,037	178,824	178,444	181,880
Pork	Sabah	9,268	9,016	8,237	9,109	7,802	7,941	7,805	8,538	8,636	7,157
(M. Tan/M. Ton)	Sarawak	31,087	33,436	33,494	30,034	31,965	36,525	40,227	41,169	40,942	40,715
Jumlah	*Total*	220,860	219,265	202,688	198,337	211,953	247,147	228,068	228,531	228,023	229,752
DAGING AYAM/ITIK	S. Malaysia	679.36	685.34	926.54	993.96	1,029.09	1,104.57	1,102.21	1,182.99	1,254.24	1,286.26
Poultry Meat	Sabah	57.51	87.28	60.57	58.23	50.03	49.99	46.00	49.89	50.44	53.43
('000 M. Tan)	Sarawak	48.79	56.11	61.47	65.71	67.78	72.89	73.83	77.61	85.97	86.39
Jumlah	*Total*	785.66	828.73	1,048.59	1,117.90	1,146.90	1,227.45	1,222.04	1,301.48	1,390.66	1,427.08
TELUR AYAM/ITIK *	S. Malaysia	6,072	5,921	6,001	6,093	6,711	7,249	7,613	7,758	8,157	8,457
Chicken/Duck Eggs	Sabah	142	490	418	455	469	554	562	548	554	557
(Juta Biji/Mil. Eggs)	Sarawak	580	696	738	752	707	768	805	780	840	907
Jumlah	*Total*	6,793 ** 408	7,107 ** 426	7,157 ** 429	7,300 ** 438	7,887 ** 473	8,572 ** 514	8,980 ** 539	9,086 ** 545	9,551 ** 573	9,922 ** 595
SUSU	S. Malaysia	884.45	957.84	870.17	634.63	678.36	768.48	513.89	501.33	529.43	566.59
Milk	Sabah	7.99	15.22	16.37	14.37	7.92	9.87	9.24	11.20	12.00	12.60
(Juta Liter/Mil. Litres)	Sarawak	2.62	2.75	2.51	1.83	2.00	2.22	2.52	2.63	2.69	2.82
Jumlah	*Total*	895.06	975.81	889.05	650.83	688.28	780.57	525.65	515.16	544.12	582.01

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, 2005 – 2014 (DVS, 2014)

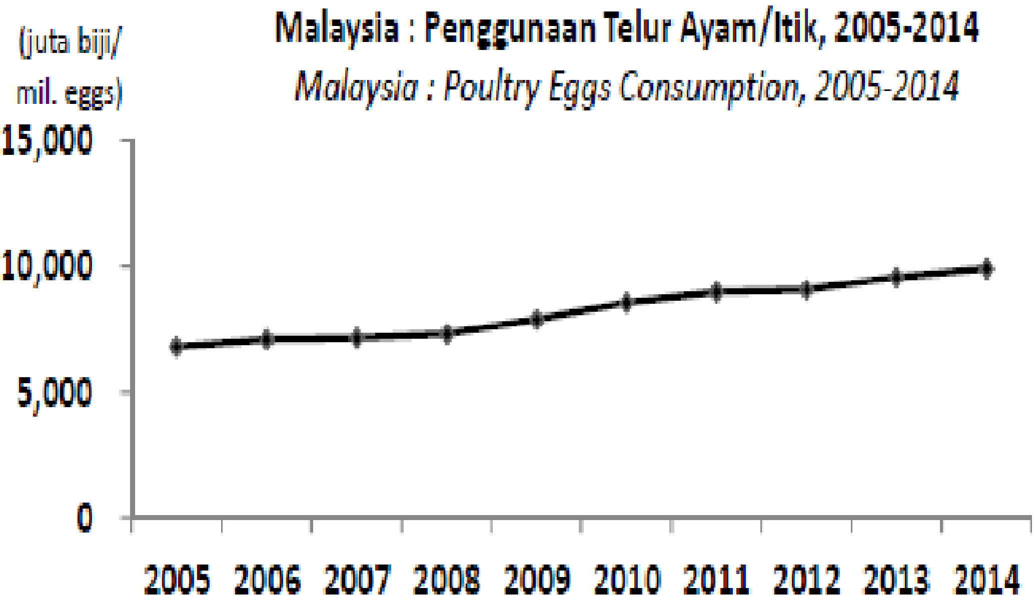

Figure A2: Poultry Eggs Consumption in Malaysia, 2005 – 2014 (DVS, 2014)

APPENDIX B: Densities for LFC-CTR, LFC-ES2.5 and LFC-ES5.0 up to 90 Days of Curing Periods

Table B1: Densities for LFC-CTR, LFC-ES2.5 and LFC-ES5.0 up to 90 Days of Curing Periods

Curing Period (Days)	Mix	Density (kg/m^3)
7	LFC-CTR	1309
	LFC-ES2.5	1349
	LFC-ES5.0	1310
28	LFC-CTR	1349
	LFC-ES2.5	1316
	LFC-ES5.0	1345
90	LFC-CTR	1294
	LFC-ES2.5	1310
	LFC-ES5.0	1301

APPENDIX C: ISAT, Sorptivity, Water Absorption and Porosity of Various Types of Specimens

Table C1: ISAT of Various Types of Specimens up to 90 Days of Curing Periods

Curing Period (Days)	Mix	Average Flow, *f* (ml/m^2/s)			
		Test Time (min)			
		10	30	60	120
7	LFC-CTR	56.15	43.13	33.60	21.92
	LFC-ES2.5	41.61	20.80	13.44	9.23
	LFC-ES5.0	40.60	15.49	9.77	7.68
28	LFC-CTR	40.25	25.72	18.16	13.80
	LFC-ES2.5	41.39	26.19	18.19	9.07
	LFC-ES5.0	39.96	25.21	11.79	7.63
90	LFC-CTR	30.94	23.22	11.80	6.56
	LFC-ES2.5	30.50	19.24	8.21	5.62
	LFC-ES5.0	27.89	18.25	9.95	5.16

Table C2: Sorptivity of Various Types of Specimens up to 90 Days of Curing Periods

Curing Period (Days)	Mix	Sorptivity, *I* (× 10^{6}mm) per 1000 kg/m^3								
		Time (s)								
		60	300	600	900	1800	3600	5400	7200	9000
7	LFC-CTR	0.76	1.30	1.70	2.01	2.65	3.54	4.14	4.64	5.05
	LFC-ES2.5	0.51	0.78	0.99	1.15	1.46	1.96	2.28	2.52	2.76
	LFC-ES5.0	0.65	0.90	1.09	1.25	1.57	2.03	2.37	2.59	2.81
28	LFC-CTR	0.45	0.79	1.06	1.28	1.72	2.53	3.08	3.44	3.86
	LFC-ES2.5	0.75	1.06	1.33	1.55	1.99	2.57	3.05	3.4	3.7
	LFC-ES5.0	0.72	0.96	1.21	1.39	1.81	2.35	2.79	3.14	3.37
90	LFC-CTR	0.69	1.07	1.44	1.64	2.21	3.03	3.59	4.07	4.44
	LFC-ES2.5	0.80	1.04	1.28	1.47	1.80	2.24	2.52	2.90	3.21
	LFC-ES5.0	0.57	0.72	0.97	1.08	1.38	1.78	2.19	2.45	2.67

Table C3: Water Absorption and Porosity of Various Types of Specimens up to 90 Days of Curing Periods

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	1.16	1.45	1.05	74.26	25.29
	LFC-ES2.5	1.10	1.35	0.97	66.50	22.51
	LFC-ES5.0	1.18	1.41	1.05	66.19	20.08
28	LFC-CTR	1.19	1.47	1.12	79.49	23.52
	LFC-ES2.5	1.15	1.40	1.04	69.81	21.95
	LFC-ES5.0	1.17	1.43	1.02	21.55	62.2
90	LFC-CTR	1.11	1.42	1.02	77.31	27.85
	LFC-ES2.5	1.11	1.42	1.00	74.09	27.48
	LFC-ES5.0	1.19	1.48	1.09	70.87	24.87

APPENDIX D: Compressive Strength, UPV and Performance Index of Various Types of Specimens

Table D1: Compressive Strength, Ultrasonic Pulse Velocity and Performance Index of Various Types of Specimens up to 90 Days of Curing Periods

Curing Period (Days)	**Mix**	**Compressive Strength, f_c (MPa)**	**UPV (km/s)**	**Performance Index, *PI* (MPa/1000kg/m^3)**
7	LFC-CTR	4.89	1.844	3.75
	LFC-ES2.5	4.60	1.860	3.72
	LFC-ES5.0	5.43	1.875	4.16
28	LFC-CTR	5.31	1.911	4.44
	LFC-ES2.5	5.24	1.935	4.56
	LFC-ES5.0	6.22	1.952	5.03
90	LFC-CTR	5.43	1.937	4.44
	LFC-ES2.5	5.89	1.950	4.66
	LFC-ES5.0	6.57	1.965	5.08