DURABILITY OF FOAMED CONCRETE WITH PROCESSED SPENT BLEACHING EARTH AS PARTIAL REPLACEMENT OF CEMENT UNDER CHLORIDE ENVIRONMENT

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ABSTRAK

Dahulu, penggunaan bahan-bahan pozzolan seperti abu terbang, silikon silika dan tanah sangkar letupan relau granulated sebagai penggantian dalam pengeluaran konkrit telah membuktikan untuk meningkatkan daya tahan konkrit akibat kesan pozzolanicnya. Selain itu, penggunaan bahan-bahan pozzolan dari sisa industri sebagai bahan binaan membawa kepada pengurangkan kos bahan binaan dan mengurangkan kesan alam sekitar dari sisa buangan. Processed Spent Bleaching Earth (PSBE) adalah SBE yang telah dirawat dan boleh digunakan sebagai pengganti sebahagian untuk simen dalam konkrit berbuih akibat kesan pozzolanicnya. Objektif kajian ini adalah untuk mengkaji kesan Processed Spent Bleaching Earth dalam meningkatkan ketahanan konkrit berbuih terhadap serangan klorida. Empat campuran konkrit berbuih direkabentuk untuk ketumpatan 1600 kg/m3. Campuran konkrit berbuih (FC) dengan 100% OPC direka sebagai campuran kawalan asas. Konkrit berbuih mengandungi Processed Spent Bleaching Earth sebagai pengganti sebahagian untuk simen direka dengan 10%, 20% dan 30% daripada PSBE mengikut berat simen iaitu dinamakan sebagai PFC1, PFC2 dan PFC 3 masing-masing. Dalam kajian ini, spesimen kubus 100mm x 100mm x 100mm dan spesimen silinder 200 mm diameter x 100mm telah disediakan dan diuji berdasarkan ASTM C513-11 dan ASTM C1202 untuk kekuatan mampatan dan daya tahan konkrit berbuih ke persekitaran klorida. Semua spesimen telah mengalami pengawetan air selama 28 hari sebelum direndam dalam larutan natrium klorida 5% dengan pH 6.5 untuk 7, 28, 60 dan 90 hari. Spesimen konkrit berbuih diperhatikan setiap minggu di mana fizikal dan pengurangan berat spesimen diukur pada setiap minggu sehingga akhir prosedur ujian. Spesimen silinder disediakan untuk ujian kebolehtelapan klorida pesat (RCPT) dan uji kekonduksian terma. Kajian menunjukkan bahawa spesimen yang mengandungi PSBE mengalami peratusan perubahan berat yang lebih rendah berbanding dengan spesimen kawalan. Keputusan menunjukkan bahawa 30% PSBE melakukan prestasi yang lebih baik dalam kekuatan dan ketahanan konkrit berbuih terdedah kepada persekitaran klorida. Di samping itu, kemerosotan fizikal bagi 30% PSBE konkrit adalah lebih rendah daripada campuran kawalan. Oleh itu, integrasi PSBE sebagai pengganti simen separa meningkatkan rintangan konkrit berbuih ke persekitaran klorida.

ABSTRACT

Formerly, the uses of the pozzolan materials such as fly ash, silica fume and ground granulated blast-furnace slag as replacement in the production of the concrete have proven to increase the durability of the concrete due to its pozzolanic effect. Besides the utilization of pozzolan materials from the industrial waste as a construction materials lead to reduce the cost of construction materials and reduce the environmental impact from the waste. Processed Spent Bleaching Earth (PSBE) is the SBE that has been treated and can be used as a partial replacement for cement in the foamed concrete due to its pozzolanic effect. The objective of the study is to investigate the effect of the Processed Spent Bleaching Earth in increasing the durability of the foamed concrete against chloride attack. Four mixtures of foamed concrete were design for density of 1600 kg/m^3. Foamed concrete (FC) mix with 100% OPC was designed as basic control mix. Processed Spent Bleaching Earth Foamed Concrete mixes (PFC) were designed by partial replacement of cement with 10%, 20% and 30% of PSBE by weight of cement namely as PFC1, PFC2 and PFC 3 respectively. In this study, cube specimen 100mm x 100mm x 100mm and cylinder specimen 200mm diameter x 100mm were prepared and tested based on ASTM C513-11 and ASTM C1202 for compressive strength and durability of foamed concrete towards chloride environment. All specimens were subjected to water curing for 28 days before immersed in the 5% Sodium Chloride solution with pH 6.5 for 7, 28, 60 and 90 days. The behaviour of foamed concrete specimen was observed weekly where the physical and mass loss of the specimens was measured at every week until the end of testing procedure. The cylinder specimens were prepared for rapid chloride permeability test (RCPT) and thermal conductivity test. The findings showed that specimens containing PSBE experienced lower percentage of mass change as compared to control specimen. Results exhibit that 30% of PSBE performed better performance in strength and durability of foamed concrete exposed to chloride environment. In addition, the physical deterioration of 30% of PSBE was lower than control mixture. Hence, the integration of PSBE as partial cement replacement enhances the resistance of foamed concrete towards chloride environment.

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LIST OF SYMBOLS

%	Percentage
A	Cross sectional area
c	Specific Heat Capacity
H	Thickness of specimen
K	Thermal conductivity
m	Cube mass
Q	Heat Conduction
T	Time
T_1	Temperature of hot plate
T_2	Temperature of cold plate

LIST OF ABBREVIATIONS

Al_2O_3	Aluminium Oxide
ASTM	American Society for Testing and Materials
BS En	British Standard European Norm
C_2S	Dicalcium Silicate
C_3A	Tricalcium Aluminate
C_3S	Tricalcium Silicate
C_4AH	Tetracalcium Alumino Ferite
$Ca(OH)_2$	Calcium Hydroxide
Ca_3SiO_5	Tricalcium Silicate
$CaCl_2$	Calcium Chloride
CaO	Calcium Oxide
CO_2	Carbon Dioxide
C-S-H	Calcium Silicate Hydrate
FC	Foamed Concrete
Fe_2O_3	Ferric Oxide
FKASA	Fakulti Kejuruteraan Awam dan Sumber Alam
g	Gram
H_2O	Water
J/s	Joule per second
K	Kelvin
K_2O	Potassium Oxide
kg	Kilogram
kg/m^3	Kilogram per meter cube
kN	Kilo Newton
m	Meter
m^2	Meter square
MgO	Magnesium Oxide
ml	Milliliter
mm	Millimeter
MnO_2	Manganese Dioxide
MPa	Mega Pascal
Na_2O	Sodium Oxide
NaCl	Sodium Chloride
NaOH	Sodium Hydroxide

OPC	Ordinary Portland Cement
P_2O_5	Phosphorus Pentoxide
PFC	Processed Spent Bleaching Earth Foamed Concrete
pH	Potential of hydrogen
PSBE	Processed Spent Bleaching Earth
RCPT	Rapid Chloride Permeability Test
s	Second
SBE	Spent Bleaching Earth
SiO_2	Silicon Dioxide
SSD	Saturated Surface Dry
TiO_2	Titanium Dioxide
UiTM	Universiti Teknologi MARA
UK	United Kingdom
UMP	Universiti Malaysia Pahang
US	United States
UTM	Universal Testing Machine
V	Volt
w/c	Water/Cement
W/mK	Watts per square metre

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Utilization of concrete gives negative impacts to environment due to the production of cement consumes a lot of energy, raw materials, and carbon dioxide (CO_2) emission which lead to greenhouse effect. Hence, the concrete manufacturers are focusing on reducing the use of Ordinary Portland Cement (OPC) due to the estimation of emit 0.8-0.9 ton of Carbon Dioxide (CO_2) per ton of cement (Yang, Lee, Song, & Gong, 2014). Currently, pozzolan material is used to replace cement due to its pozzolanic effect. Pozzolan in concrete contributes to compressive strength in two ways which are by pozzolanic reaction and filler effect. Concrete with pozzolanic material contents can reduce permeability and enhance the durability of concrete (Aprianti S, 2015). From previous researcher, adding pozzolans into concrete is more effective than decreasing water/cement ratio in order to reduce permeability of chloride into concrete (Faiz U A Shaikh & Supit, 2015). Concrete interacts with chloride, the reinforcements inside concrete will be damaged and corrode faster than usual (Ragab, Elgammal, Hodhod, & Ahmed, 2016). Pozzolanic reaction tend to occur when the hydration process is fast where it create large amount of lime and initial water curing for at least 7 days is required. The product of pozzolanic reaction has C-S-H Gel where these gels will fill the voids in concrete. Thus the concrete created will be denser. Moreover, the amount of Calcium Hydroxide ($Ca(OH)_2$) will be reduced and it will enhance the durability of concrete.

Rice husk ash, sugarcane bagasse ash, hazel nutshell ashes and wheat straw ash are examples of wastes that are pozzolanic waste materials and can be used to replace cement (Aprianti S, 2015). Spent bleaching earth (SBE) is originated from the degumming and bleaching of crude palm oil and SBE is commonly disposed to landfills.

This disposal is costly and causes environmental degradation. In Malaysia nowadays, SBE is being disposed to landfills that have potential to cause fire, pollutions, hazards and green-house gas emissions (Loh et al., 2013). The residual oil from SBE will rapidly oxidizes to spontaneous auto ignition-point and giving out unpleasant odours (Mana, Ouali, de Menorval, Zajac, & Charnay, 2011). Malaysia is one of the largest producers for palm oil product in the world. So, the wastes will be generated are large in quantity. Spent Bleaching Earth (SBE) is a waste that hard to manage due to the large quantity produce, the nature of itself and the lack of way to recover it (Krzyśko-Łupicka, Cybulska, Wieczorek, Możdżer, & Nowak, 2014).

Foamed concrete is being used widely due to its' light weight property. The first ever Portland cement based foamed concrete was patented by Axel Eriksson in 1923 (Amran, Farzadnia, & Ali, 2015). In United Kingdom (UK), foamed concrete had been widely used in highway construction since 1970, but foamed concrete only being recognised as a building material at 1980 (Decký et al., 2016). Foamed concrete is low in density with the range of 400-1850kg/m^3. Air void distribution is one of the most important factors affect the strength (Hilal, Thom, & Dawson, 2015). Foamed concrete has a lot advantages over ordinary concrete in manipulation, possibility of treatment and repairing (Kuzielová, Pach, & Palou, 2016). Due to its low density, foamed concrete is widely used as thermal and sound insulation materials in construction. The thermal conductivity of foamed concrete is around 0.66 W/mK at density of 1600 kg/m^3. Meanwhile, thermal conductivity of normal concrete is 1.6 W/mK at density of 2200 kg/m^3 which is 59% higher than foamed concrete (Amran et al., 2015). When the density is reduced by 100 kg/m^3, there will be a drop of 0.04 W/mk of total thermal insulation in the case of foamed concrete. Volume of air in foamed concrete create space and it makes foamed concrete is good in thermal resistivity (Alengaram et al., 2013). The high porosity of foamed concrete makes them as a good thermal insulation material (Miled & Limam, 2016). However, there are several researchers claimed that the chloride ion resistance of concrete is depending more on porosity and inter-connectivity of the pore system and it not much depending on the chemical bonding capacity of cement (Faiz Uddin Ahmed Shaikh, 2016). Generally, durability of concrete is affected by chloride penetration subjected by sea water, de-icing salts and chloride-bearing air in marine areas. Corrosion of concrete occurred due to expansive products produced in the reaction of chloride ions with components of concrete such as $Ca(OH)_2$.

The performance of foamed concrete against chloride ingress is equivalent to an ordinary concrete with compressive strength of 25 MPa. Chloride ion and carbon dioxide will destroy the protective ferric oxide film which is stable in alkaline environment around reinforcement bar.

Thus, this study is to investigate the durability of Processed Spent Bleaching Earth (PSBE) as a partial cement replacement in foamed concrete properties under chloride environment and thermal conductivity. The objectives of this study are to investigate the compressive strength and percentage strength loss, percentage of mass change and physical deterioration of foamed concrete mixture containing 0 to 30% PSBE when exposed to chloride environment and durability of foamed concrete in term of chloride penetration and thermal conductivity of foamed concrete mixtures containing 0 and 30% PSBE.

1.2 PROBLEM STATEMENT

Utilization of concrete gives negative impacts to environment due to the production of cement consumes a lot of energy, raw materials, and carbon dioxide (CO_2) emission which lead to greenhouse effect. Globally, cements product are categories as the second most consume substance in the world whereas the first in rank is the water (Shen et al., 2014). It should be noted that, the concrete manufacturers are focusing on reducing the use of Ordinary Portland Cement (OPC) due to the estimation of emit 0.8-0.9 ton of Carbon Dioxide (CO_2) per ton of cement (Yang et al., 2014).

Foamed concrete has a lot advantages over ordinary concrete in manipulation, possibility of treatment and repairing (Kuzielová et al., 2016). Due to its low density, foamed concrete is widely used as thermal and sound insulation materials in construction. However, there are several researchers claimed that the chloride ion resistance of concrete is depending more on porosity and inter-connectivity of the pore system and it not much depending on the chemical bonding capacity of cement (Faiz Uddin Ahmed Shaikh, 2016). Principally, durability of concrete is affected by chloride penetration subjected by sea water, de-icing salts and chloride-bearing air in marine areas. Corrosion of concrete occurred due to expansive products produced in the reaction of chloride ions with components of concrete such as $Ca(OH)_2$. Chloride ion and carbon dioxide will destroy the protective ferric oxide film which is stable in alkaline environment around reinforcement bar.

Spent bleaching earth (SBE) is originated from the degumming and bleaching of crude palm oil and SBE is commonly disposed to landfills. This disposal is costly and causes environmental degradation. In Malaysia nowadays, SBE is being disposed to landfills that have potential to cause fire, pollutions, hazards and green-house gas emissions (Loh et al., 2013). The residual oil from SBE will rapidly oxidizes to spontaneous auto ignition-point and giving out unpleasant odours (Mana et al., 2011). Malaysia is one of the largest producers for palm oil product in the world. So, the wastes will be generated are large in quantity. Spent Bleaching Earth (SBE) is a waste that hard to manage due to the large quantity produce, the nature of itself and the lack of way to recover it (Krzyśko-Łupicka et al., 2014). Processed Spent Bleaching Earth (PSBE) is the SBE that has been treated and can be used as a partial replacement for cement in the foamed concrete due to its pozzolanic effect.This study is to investigate the durability of Processed Spent Bleaching Earth (PSBE) as a partial cement replacement in foamed concrete properties under chloride environment. By utilization of PSBE from the industrial waste as a construction materials lead to reduce the environmental impact due to cement production or from waste and also to reduce the cost of construction materials.

1.3 OBJECTIVE OF STUDY

The goal of this research is to study the effect of PSBE on strength and durability of foamed concrete under chloride environment as follow:

i. To investigate the compressive strength of the foamed concrete mixtures containing 0 to 30% PSBE
ii. To investigate the durability of foamed concrete mixtures containing 0 to 30% PSBE in term of percentage strength loss when exposed to chloride attack and water.
iii. To investigate the durability of foamed concrete mixtures containing 0 to 30% PSBE in term of percentage mass change when exposed to chloride attack and water.

iv. To investigate the durability of foamed concrete mixtures containing 0 to 30% PSBE in term of the physical deterioration when exposed to chloride attack and water.

v. To investigate the thermal conductivity of the PSBE foamed concrete mixtures containing 0 to 30% PSBE.

vi. To investigate the chloride penetration of the PSBE foamed concrete mixtures containing 0 and 30% PSBE.

1.4 SIGNIFICANT OF STUDY

The integration of PSBE as partial cement replacement in foamed concrete has greatly influenced on the foamed concrete strength and durability. The findings exhibit that foamed concrete containing PSBE enhances the resistance of foamed concrete under chloride environment. Hence, the usage of PSBE from the industrial waste as a construction materials lead to reduce the environmental impact due to less cement usage or from disposal of SBE and also to reduce the cost of construction materials. With this, environmental degradation can be lowered and establish sustainability development in Malaysia.

1.5 SCOPE OF STUDY

The study was focused on the effect of Processed Spent Bleaching Earth (PSBE) as partial cement replacement in compressive strength and durability of foamed concrete under chloride environment. Four mixtures of foamed concrete were design for density of 1600 kg/m^3. Foamed concrete (FC) mix with 100% OPC was designed as basic control mix. Processed Spent Bleaching Earth Foamed Concrete mixes (PFC) were designed by partial replacement of cement with 10%, 20% and 30% of PSBE by weight of cement namely as PFC1, PFC2 and PFC 3 respectively. In this study, cube specimen 100mm x 100mm x 100mm and cylinder specimen 200mm diameter x 100mm were prepared and tested based on ASTM C513-11 and ASTM C1202 for compressive strength and durability of foamed concrete towards chloride environment. All specimens were subjected to water curing for 28 days before immersed in the 5% Sodium Chloride solution with pH 6.5 for 7, 28, 60 and 90 days. The behaviour of foamed concrete specimen was observed weekly where the physical and mass loss of the specimens was measured at every week until the end of testing procedure. The cylinder specimens were prepared for rapid chloride penetration test (RCPT) and thermal conductivity test. This study was carried out at Concrete Laboratory of Faculty of Civil Engineering & Earth Resources (FKASA) in Universiti Malaysia Pahang (UMP).

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter was discussed the history, application, constituents of materials and properties of foamed concrete that has been review from previous researchers.

2.2 FOAMED CONCRETE

Foamed concrete is widely used in construction area in many countries such as German, Thailand and Turkey. In history, Romans is the first to realize that animal blood is added into a mix of coarse sand and small gravel with hot lime and water and then stir its. Then, small air bubbles are formed thus the mix is more workable and durable (Amran, Farzadnia, & Ali, 2015). Somehow, the first ever Portland cement based foamed concrete was patented by Axel Eriksson in 1923 (Amran et al., 2015). In United Kingdom (UK), foamed concrete had been widely used in highway construction since 1970, but foamed concrete only being recognised as a building material at 1980 (Decký et al., 2016).

In definition, foamed concrete consider as light cellular concrete and can be classified as lightweight concrete with entrapped air. Foamed concrete is low in density with the range of 400-1850 kg/m^3. From time to time, volume, size, air voids and the density of foamed concrete is investigating by professionals in term of strength. Air void distribution is one of the most important factors affect the strength (Hilal, Thom, & Dawson, 2015). If the air void distribution is narrower, the strength is higher. Foamed concrete has a lot advantages over ordinary concrete in manipulation, possibility of treatment and repairing (Kuzielová, Pach & Palou, 2016). Foam concrete is famous for its low density, high workability, good mechanical strength, low thermal conductivity, less aggregate usage and good in thermal insulation. Besides, foamed concrete has textural surface and micro-structural cells and its can enhance the thermal conductivity, fire resistance and sound absorbance. Besides that, the mixing is simple and fast and it reduces the construction time. Foamed concrete has low failure rate, it is not easy to fail due to bacteria, funguses and hydrocarbons (Decký et al., 2016).

In the field of civil and structural engineering, foamed concrete had been widely used due to the distinctive properties like low thermal insulation, low density, high workability, cost-effectiveness when repair or rehabilitation and simple to construct. For example, foamed concrete with high density is used in structural construction whereas low density foamed concrete is used for cavity filling. Then, foamed concrete is favourite material used as superlative material for voids such as basements, pipes and sewer lines due to the high workability property. Another application of foamed concrete is used to construct retaining wall and track of jogging due to the low cement usage and high workability (Ma & Chen, 2016). Foamed concrete also used as energy-absorbing materials to protect the immersed military structures (Miled & Limam, 2016). In Holland, foamed concrete usually used as road sub-base because the transport load is not so heavy (Amran et al., 2015).

2.3 CONSTITUENT MATERIALS OF FOAMED CONCRETE

2.3.1 Cement

In foamed concrete, the amount of cement used is higher than conventional concrete when the required compressive strength is the same. The reason is the bonding between particles in foamed concrete is weak as compare to normal concrete, so the particles in foamed concrete is hard to retain as a mono structure. Cement paste is the main component of mortar and concrete. It is a material which has complex porous structure with the pores ranging from nanometers to micrometers (Stepišnik & Ardelean, 2016). Thus, controlling the fluidity properties of cement paste is important to produce quality concrete (Zhu, Zhang, Zhang, & Yao, 2017). The cement paste is formed from hydration process. When cement mixing with water, there are several chemical reaction will occur. One of the chemical reaction processes is hydration process, hydration is considered as a chemical process with the formation of hydrates. The main component of hydration process is Calcium Silicate Hydrate gel (C-S-H) and $Ca(OH)_2$ where it is a non-binder and vulnerable to chemical attack. The cement paste's porosity is divided into two components which are inter-particle porosity or called as capillary porosity and gel porosity (Rahimi-Aghdam, Bazant, & Abdolhosseini Qomi, 2017). The inter-particle porosity will be filled by hydration products such as C-S-H gel where it make the concrete harden. C-S-H gel will affect the setting and hardening, strength and dimensional stability of concrete.

Portland cement is not a simple chemical compound and it contains 4 main compounds namely Tricalcium Silicate (C_3S), Dicalcium Silicate (C_2S), Tricalcium Aluminate (C_3A) and Tetracalcium Alumino Ferite (C_4AH). Each of the compounds has their own unique functions. For Tricalcium silicate (C_3S), it hydrates rapidly and contributes towards early strength development. Meanwhile, Dicalcium Silicate (C_2S) hydrates slightly slower due to its' less reactive property and it contribute towards belated strength development. Then, Tricalcium Aluminate (C_3A) is an essential content in cement and contributes slightly towards early strength development. Due to the reaction is superior fast and releasing high heat, it may lead to "Flash Set" and thus Gypsum is needed to slow down the reaction.

The cement industry will still play as an important role in future development even though it contributes significantly to pollution. In cement production process, Carbon Dioxide (CO_2) is emitted from three different sources. The direct emission of CO_2 is from the combustion of fossil fuel and calcination of calcium carbonate in processing stage. Then, electricity generated from raw materials transportation, electrical motors and electrical facilities are indirect emission of CO_2. There are approximately 90% of CO_2 is from direct emission while 10% is from the convey of raw material and other production processes (Gao et al., 2015).

2.3.2 Sand

Sand to cement ratio can control the strength of concrete. When the amount of sand use is increases, the usage of cement will be decreased. However, the lower consumption of cement causes lower hydration process rate as compare to normal concrete. The addition of waste material that can perform pozzolanic reaction and provide secondary C-S-H Gel to concrete may cause the hydration process in normal rate. Natural sands have variety of mineralogic compositions and chemical characteristics. Different sand may give different strength of concrete (Hasdemir, Tuğrul, & Yilmaz, 2016).

2.3.3 Water

The amount of water needed for concrete mixing is depending on the content of constituent and the usage of admixture. Content of water will definitely affect the workability, stability, uniformly and consistency of concrete mix. Normally, the water to cement ratio in practice is approximately from 0.4 to 1.25 or about 6.5% to 14% of the desired mix density. However, the optimum water/cement ratio is 0.5 and 0.6. When water content is low, the mix will be too stiff and the bubbles will break during mixing time resulting increased in density (E. K K Nambiar & Ramamurthy, 2006). Meanwhile, if the water content is too high, the slurry will relatively thin to hold the bubbles and it causes segregation of the foam from the mix (E. K Kunhanandan Nambiar & Ramamurthy, 2006). Thus, the final density will increase. Normally, the water used for foamed concrete should be clean and can be drink. Organic content might affect the quality of protein based foam agent (Amran et al., 2015).

2.3.4 Foaming Agent

The foamed concrete density is depending on the foam agents which produces air bubbles in a mix whereas this air bubbles are named as enclosed air voids. There are several types of foaming agents that are detergents, resin soap, saponin, protein-based, hydrolysed protein synthetic and glue resins. These foaming agents have their own advantages and abilities as compare to each other. Generally, protein-based foaming agents are widely used in industry. This is because protein-based foam agents produce stronger and more closed-cell bubble structure which enable it entrap large amount of air and enable more stable air void network (Tikalsky, Pospisil, & MacDonald, 2004). Generally, the air void is approximately ranging from 6% to 35% of the total volume of desired mix (Panesar, 2013). The content of foam agents will affect the properties of both hardened and fresh concrete. The workability of the mix will drop as the volume of foam is too much (Nambiar EKK, 2008). The longer the mixing time, the entrap air will be more but too long mixing time will cause loss of entrapped air as the air content will drop. The quality of foam is a main factor to affect the strength and stiffness of a foamed concrete (E. K Kunhanandan Nambiar & Ramamurthy, 2006). The strength of foam concrete is depending on foam content as well as the type of foam agent.

2.4 PROPERTIES OF FOAMED CONCRETE

2.4.1 Density

Generally, density is defined as a volumetric mass of a material for 1 litre of the material where the density of foamed concrete is measured during both harden and fresh states. Density of a concrete can be categories as dry density and wet/fresh density. Normally, the allowable differences between dry and wet density is approximately 100-120 kg/m^3. The wet density can be measured by filling foamed concrete into a known volume and known weight of container. The maximum allowable difference of dry density for a foamed concrete mix is 50 kg/m^3 whereas it is up to $\pm$100 kg/m^3 for a high density foamed concrete that is 1600 kg/m^3. The reason to know the fresh density is to prepare the actual design volume for mix and casting control, meanwhile dry density is measured to control physical, mechanical and durability properties of hardened foamed concrete. Wet density of foamed concrete normally decreases as the foam volume content increases (Amran et al., 2015).

2.4.2 Workability

Workability is the ability of fresh concrete to flow and fill the void volume without undergoing any compaction and vibration works. The workability of foamed concrete is good due to the air voids in fresh mix with the addition of stable foam agent. For the workability test, slump test is not suitable for testing low density mix such as foamed concrete. The workability of a mix commonly control by water cement ratio and content of foaming agents. The smaller particles size and has bigger surface area of pozzolan particles are more workable as compare to normal concrete with 100% cement mixture. The reason is that the fineness natural pozzolan enable the fresh concrete more flowable and workable. The plasticizers are not recommended to add in foamed concrete unless the amount is not more than 0.2% weight of cement (Amran et al., 2015).

2.4.3 Compressive Strength

Compressive strength is the ability of a concrete to remain the original current state and withstand the maximum loading force until it fail. The compressive strength of a concrete is affected by several factors such as rate of foam agent, different water content, different cement content, different sand content, size particle type, additional ingredients and density. Generally, concrete with high content of cement will have high compressive strength, whereas concrete with high content of water will have low compressive strength. Density of foam agent is one of the main factors that affect the compressive strength with the variation amount of air void in different density in hardened foamed concrete. When the amount of foam agent is too much, the compressive strength will be lowered due the higher amount of air void created by foam agent. The another main controlling factor is water cement ratio, the consistency and stability of mix can be enhanced by using appropriate amount of water and the large size of foam bubbles can be reduced which resulted in increasing compressive strength. To achieve higher strength in foamed concrete design, the recommended water cement ratio or binder ratio are 0.19 and 0.17 (Amran et al., 2015). The compressive strength is also depending on the amount of sand with respect to binder in foamed concrete. Moreover, the compressive strength of hardened concrete is decrease when there is excessive amount of coarse sand. The strength is decreased due to the pore size will be affected. However, the strength of concrete can be enhanced by using fine sand with regular distribution of pores.

2.4.4 Durability

The performance of foamed concrete against chloride ingress is equivalent to an ordinary concrete with compressive strength of 25 MPa. One of the main reasons of degradation of concrete is due to chemical attack. One of the chemical attacks is chloride ingression and it penetrates through concrete cover and then chemically reacts to form dust to the reinforcement. Chloride ion and carbon dioxide will destroy the protective ferric oxide film which is stable in alkaline environment around reinforcement bar. There are several researchers claimed that the chloride ion resistance of concrete is depending more on porosity and inter-connectivity of the pore system and it not much depending on the chemical bonding capacity of cement (Faiz Uddin Ahmed Shaikh, 2016). Generally, durability of concrete is affected by chloride penetration subjected by sea water, de-icing salts and chloride-bearing air in marine areas. Corrosion of concrete occurred due to expansive products produced in the reaction of chloride ions with components of concrete such as $Ca(OH)_2$. The example of expansive product is alkaline calcium chloride $Ca(OH)_2 \cdot H_2O \cdot CaCl_2$ which this product increases its volume during crystallization and damage to concrete.

$$Ca(OH)_2 + 2NaCl \rightarrow CaCl_2 + 2NaOH$$

$$Ca(OH)_2 + CaCl_2 + H_2O \rightarrow Ca(OH)_2 \cdot H_2O \cdot CaCl_2$$

In addition, chloride ions from de-icing salts will cause deterioration as well (Zych, 2014).

2.4.5 Thermal Conductivity

The high thermal insulation of foamed concrete is one of the advantages of the light weight concrete. Since foamed concrete is low in density, thus it is widely used as thermal and sound insulation materials in construction. The thermal conductivity of foamed concrete is around 0.66 W/mK at density of 1600 kg/m^3. Meanwhile, thermal conductivity of normal concrete is 1.6 W/mK at density of 2200 kg/m^3 which is 59 per cent higher than foamed concrete in thermal insulation (Amran et al., 2015). When the density is reduced by 100 kg/m^3, there will be a drop of 0.04 W/mk of total thermal insulation in the case of foamed concrete. The degree of thermal insulation of foamed concrete is affected by the mixing composition of mineral admixtures and type of aggregate. Thermal conductivity is mainly depends on the density and pores of the mixture. The thermal conductivity is high when the density is high. Volume of air in foamed concrete create space and it makes foamed concrete is good in thermal resistivity (Alengaram et al., 2013). The high porosity of foamed concrete makes them as a good thermal insulation materials (Miled & Limam, 2016).

2.5 EFFECT OF POZZOLANIC MATERIAL

2.5.1 Pozzolanic Reaction

Pozzolanic reaction occur when there is present of Calcium Hydroxide ($Ca(OH)_2$) and the present of water is enough for the pozzolanic reaction to form secondary C-S-H Gel. The C-S-H Gel can be expressed as:

$$2Ca_3SiO_5 + 7H_2O \rightarrow 3CaO \cdot 2SiO_2 \cdot 4H_2O + 3Ca(OH)_2 + 173.6Kj$$

Pozzolanic reaction tend to occur when the hydration process is fast where it create large amount of lime and initial water curing for at least 7 days is required. The product of pozzolanic reaction has C-S-H Gel where these gels will fill the voids in concrete. , thus the concrete created will be denser. Moreover, the amount of Calcium Hydroxide ($Ca(OH)_2$) will be reduced and it will enhance the durability of concrete.

Some of the waste which is pozzolanic by-product can be used as environmental friendly material for greening construction. Rice husk ash, sugarcane bagasse ash, hazel nutshell ashes and wheat straw ash are examples of wastes that are pozzolanic waste materials and can be used to replace cement (Aprianti S, 2015). Pozzolan materials mix with Portland cements to form cementitious properties, however they do not have any cementitious properties by themselves. Thus, a cementitious material can self-cementitious and it contains CaO while a pozzlanic material need ($Ca(OH)_2$) to form strength. Pozzolan in concrete contributes to compressive strength on two ways which are by pozzolanic reaction and filler effect. Concrete with pozzolanic material contents can reduce permeability and enhance the durability of concrete (Aprianti S, 2015).

From previous researcher, adding pozzolans into concrete is more effective than decreasing water/cement ratio in order to reduce permeability of chloride into concrete (Faiz U A Shaikh & Supit, 2015). Generally, pozzolanic reaction is taking place on the surface of particles, so increasing the surface area of particles has significant effect on pozzolanic activity. Then, the fineness of pozzolan is essential to enhance the cement paste aggregate interfacial zone where it is the weakest link in concrete. Pozzolanic reaction is slow as compared to the hydration process of Portland Cement, this is the reason why concretes with high volumes of pozzolanic materials have low early age strength. However, pozzolanic materials are more effective in enhancing concrete properties at later ages due to the higher pozzolanic reaction rate in a longer period.

2.6 PROCESSED SPENT BLEACHING EARTH

Spent Bleaching Earth is a waste created from edible palm oil which may use as an ingredient in foamed concrete. Spent Bleaching Earth can be processed by using solvent extraction of residual oil from bleaching method. The product of this process is called Processed Spent Bleaching Spent (PSBE) which is in solid form and it is more suitable to be used in creating more durable foamed concrete.

2.6.1 Spent Bleaching Earth

Spent bleaching earth (SBE) is originated from the degumming and bleaching of crude palm oil and SBE is commonly disposed to landfills. This disposal is costly and causes environmental degradation. Bleaching earth is in very fine powder form and the main component of bleaching earth is silicon dioxide. SBE contains high percentage of residual oil which is in between 20-40%. In Malaysia nowadays, SBE is being disposed to landfills that have potential to cause fire, pollutions, hazards and green-house gas emissions (Loh et al., 2013). The residual oil from SBE will rapidly oxidizes to spontaneous auto ignition-point and giving out unpleasant odours (Mana, Ouali, de Menorval, Zajac, & Charnay, 2011).

There are approximately 2 million tonnes of SBE is generated yearly (Beshara & Cheeseman, 2014). SBE is a waste material that is hard to manage or to dispose due to the diversified composition and high amount of water-insoluble substances such as macro-elements, micro-element, heavy metals and fatty acids (Krzyśko-Łupicka et al., 2014).

2.6.2 Processed Spent Bleaching Earth

The refining process of crude edible oils has fours operations which are degumming, bleaching, neutralization and deodorization. The bleaching step contains usage of activated clay which also called as bleaching earth. This operation produces high amount of solid wastes that normally being disposed in landfill (Mana et al., 2011).

Bleaching earth is montmorillonite and bentonote-based natural clay that have similar characteristics as zeolite (Loh et al., 2013).

Processed Spent Bleaching Earth (PSBE) is natural pozzolan that can be used as cement replacement in concrete mixing. PSBE contains reactive Silica (SiO_2) which is approximately 60.4%. The Silica in PSBE will react with Calcium Hydroxide ($Ca(OH)_2$) and water to produce C-S-H Gel where Calcium Hydroxide is produced from hydration process of cement and water.

Hydration Process

$$Cement + H_2O = C - \mathrm{S} - \mathrm{H\ Gel}\ + \mathrm{Ca}(OH)_2$$

Pozzolanic Reaction

$$SiO_2 + Ca(OH)_2 + H_2O = C - S - H\ Gel$$

Silica from PSBE will react with calcium hydroxide in pozzolanic reaction and this will reduce the calcium hydroxide content. This is beneficial because calcium hydroxide is a vulnerable material that may react with acid and may weaken the concrete. Table 2.1 below shows the comparison between properties of SBE and PSBE.

Table 2.1 Properties of SBE and PSBE

Characteristics	**SBE**	**PSBE**
Free moisture (%)	10.5	0 – 1.8
pH (20% suspension)	4.6	4.5 – 5.3
Chemical composition (%)		
SiO_2	60.4	56.9
Al_2O_3	11.55	9.24
Fe_2O_3	9.3	8.27
MgO	5.2	4.32
CaO	1.7	3.90
Na_2O	0.4	0.08
K_2O	1.2	0.96
MnO_2	N/A	0.10
TiO_2	N/A	0.90
P_2O_5	N/A	4.87

Source: Loh et al., (2013)

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter discussed the specimen preparation, production and testing set up of this present study. All the preparation was carried out at the Concrete Laboratory of Faculty of Civil Engineering and Earth Resources (FKASA) in Universiti Malaysia Pahang (UMP) except RCPT which conducted at Universiti Teknologi MARA (UiTM).

3.2 EXPERIMENTAL PROGRAM

An experiment was conducted to determine the durability characteristic of foam concrete that used Processed Spent Bleaching Earth (PSBE) as partial replacement of cement. A 100% Ordinary Portland Cement (OPC) was mixed and serves as the base control of this experiment. There are 4 mixes design used which were 100% OPC with 0% of PSBE as partial cement replacement material as control, OPC with 10% of PSBE, OPC with 20% of PSBE and OPC with 30% of PSBE. The mixed designed of OPC and OPC with 30% PSBE were compared in term of durability against chloride. 12 cubes (100mm×100mm×100mm) and 4 cylinders (Diameter 100mm×200mm) were prepared for each mix design with compressive strength and density achieved at 30MPa and 1600 kg/m^3 by following the standard ASTMC796 and ASTM 192. The specimens in cylinder form were used to determine chloride penetration by conducting Rapid Chloride Permeability Test (RCPT) according to ASTM C1202 and thermal conductivity test by following BS En 12664 (2001). Specimens in cubes form were used to test compressive strength by using method that following ASTM C513-11.

3.3 PREPARATION OF MATERIAL

3.3.1 Cement

In this study, Ordinary Portland Cement (OPC) with brand Orang Kuat was used and it was supplied by YTL Group. This cement was sieved to pass 300 micron. It was sieved by using Sieve Shaker in Heavy Structural Laboratory of Faculty of Civil Engineering and Earth Resources (FKASA) in Universiti Malaysia Pahang (UMP). Figure 3.1 shows the Ordinary Portland Cement used in foamed concrete mix casting.

Figure 3.1 Ordinary Portland Cement

3.3.2 Sand

Silica sand was supplied by Johor Silica Industries Technology Sdn. Bhd. Kuantan, Pahang and these sands were used in concrete mixes. These silica sand is high purity silica sand and its' size were controlled which it is precise in sizing as compare to common sand. The composition of silica sand is Silicon Dioxide, $SiO2$ which made up from silicon and oxygen. Figure 3.2 shows the purify silica sand is weighted for design requirement and it is used in foamed concrete mix casting.

Figure 3.2 Silica Sand

3.3.3 Water

Water is essential in foamed concrete mixing because concrete requires water for hydration and developing strength. In this study, natural clean water that is tasteless, odourless and drinkable was used by following US Environment Water Agency. The clean water is range in pH from 6.5 to 8.5. The excessive impurities in water might affect the setting time for concrete mixing, affect designed compressive strength of concrete and also affect the durability of concrete. Figure 3.3 shows water is weighted for design requirement and it is used in foamed concrete mix casting.

Figure 3.3 Water

3.3.4 Foaming Agent

In this research study, protein-synthetic foaming agent was used. This foaming agent was manufactured by LMC Technology Sdn. Bhd which locates at Kuantan, Pahang and the foam machine by LCM. The density of foam was in the range 50 kg/m^3 to 60 kg/m^3. The foam was produced by mixing 1 litre of foam agent and 25 litre of clean water in foam generator with air compressor. Pre-foamed foam method was used and it is according to LCM guideline. Figure 3.4 shows the foam is weight to get density of 50 to 60 kg/m^3. Figure 3.5 shows the protein based foam agent. Foam is prepared by using air compress and foam generator as shown in figures 3.6 and 3.7.

Figure 3.4 Foam

Figure 3.5 Foam Agent

Figure 3.6 Air Compressor

Figure 3.7 Foam Generator

3.3.5 Processed Spent Bleaching Earth

In this investigation, the Processed Spent Bleaching Earth (PSBE) was supplied by Eco Innovation Sdn, Bhd. The PSBE was produced by following ASTM C618-12 (2012) and it was sieved to pass through 300 micron in accordance with standard ASTM E11:01(US) and EN 933-1(European). It was also regulated by international standard of ISO 565:1990 using Sieve Shaker in Heavy Structural Laboratory of Faculty of Civil Engineering and Earth Resources (FKASA) in Universiti Malaysia Pahang (UMP). Figure 3.8 shows the Processed Spent Bleaching Earth that had been sieved to pass through 300 micron.

Figure 3.8 Processed Spent Bleaching Earth

3.4 PREPARATION OF SPECIMEN

Foamed concrete used in this study was made by mixing of cement, sand, water, foam and additional additive which it is Processed Spent Bleaching Earth (PSBE). Firstly, the cement paste was produced by using mix design that had been prepared early. Cement, silica sand and PSBE mixed in dry for few minutes, then add water and mixed until get homogenous slurry. The density of slurry were recorded before and after the foam added. Density is recorded by measuring the weight of 1 liter slurry. Secondly, pre formed foam was prepared by mixing 1 liter of foam agent and 25 liter of clean water using foam machine. The machine was on and the air compression was controlled to get density ranging 50 to 60 kg/m3. Then, the foam was added into cement slurry for mixing. Mixing process continuously until get the smooth and homogenous mixed. The density of foamed concreted was recorded by measuring weight of 1 liter of mixed until get 1600 kg/m3 density. Four mixed designed were prepared which were 100% foamed concrete (FC) with 0% PSBE, FC with 10% of PSBE, FC with 20% of PSBE and FC with 30% of PSBE. Then, the 10%, 20% and 30% PSBE as cement replacement were compared to the control mix with 0% PSBE for all the experiments except RCPT. RCPT result was compared for control mixed and 30% PSBE only. All specimens were prepared for 12 cubes (100mm×100mm×100mm) for compressive strength test and 4 cylinders (Diameter 100mm×200mm) for Rapid Chloride Permeability Test and thermal conductivity test. From figure 3.9, it is showed that the inner surfaces of molds were applied of oil and figure 3.10 shows the specimen with cylinder in shape was de-molding.

Figure 3.9 Applying Oil on the Inner Surfaces of Molds

Figure 3.10 De-molding of Specimens

3.5 TESTING SET UP

3.5.1 Compression Test

This experiment was carried out after concrete cubes were immersed in water curing and chloride solution. Four concrete cubes were used for each immersion period of 7, 28, 60 and 90 days. The machine going used was 2000kN UTM machine in Heavy Structural Laboratory in UMP. The concrete cubes were taking out from the solution and let it dry in the oven for 24 hours, the weight of concretes before and after dry out were recorded. Then, the cubes were inserted into the machine and the readings of compressive strength were recorded. Standard used was ASTM C513-11. Figure 3.11 shows the foamed concrete with 0% PSBE is inserted into the compression machine and figure 3.12 shows the foamed concrete with 0% PSBE after compression test. The cracking behaviour is shown in figure 3.12.

Figure 3.11 Foamed Concrete with 0% PSBE in Compression Machine

Figure 3.12 Foamed Concrete with 0% PSBE after Compression Test

3.5.2 Thermal Conductivity Test

This test was carried out according to BS En 12664 (2001). The samples were taken out from water curing process and oven dried for 24 hours at temperature approximately 105 degree Celsius in order to remove moisture content that might be affect the results as moisture increase the heat transfer rate. Before conducting the test, samples were taken out and cool down to room temperature from oven. Then, the thermocouple was connected between hot surface, cold surface and Date Logger. Therefore, the temperatures were automatically recorded down by Date Logger at each 5 minutes for the total hours of 8. The thermal conductivity, k was calculated by using Equation 3.1.

$$k = \frac{Qh}{A(T_1 - T_2)} \qquad 3.1$$

K = Thermal conductivity, W/mK

Q = Heat Conduction, J/s

H = Thickness of specimen, m

A = Cross sectional Area, m^2

T_1= Temperature of hot plate, K

T_2 = Temperature of cold plate, K

The heat conduction, Q was calculated according to Equation 3.2. The specific heat capacity, c is 1000 J/KgK for light weight concrete based on appendix A. The total time taken for one test is 8 hours.

$$Q = [mc(T_1 - T_2)]/t \qquad 3.2$$

Q = Heat Conduction, J/s

m = Cube Mass, kg

c= Specific Heat Capacity, J/KgK

T_1 = Temperature of hot plate, K

T_2 = Temperature of cold plate, K

T = Time, s

Figure 3.13 shows the data logger used in thermal conductivity test where it is used to record the temperatures of cold plate and hot plate every five minutes automatically. Figure 3.14 shows the setting up of thermal conductivity test where the cold plate and hot plate were connected from data logger to the sample.

Figure 3.13 Data Logger

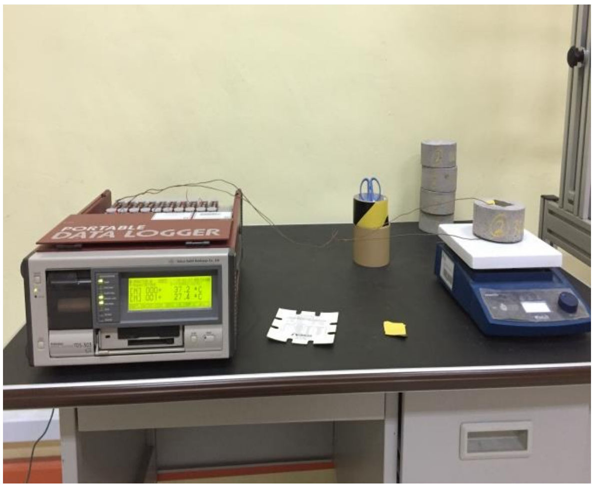


Figure 3.14 Thermal Conductivity Test

3.5.3 Durability Test (Rapid Chloride Permeability Test (RCPT)

RCPT was conducted according to ASTM C1202. After water curing for specific day which are 7, 28, 60 and 90 days, the samples were taking out from water and cut into 50mm thick. Then, the samples were oven dried for 24 hours. The samples were allowed to cold down and then the samples were wrapped. After that the samples were transported to Universiti Teknologi MARA (UiTM). After that, the best two 50mm thick samples (the middle core) from each mixed designed were chose and put into desiccator to vacuum for 3 hours. The samples were ensured to not overlap. After 3 hours, water was inserted by water entry valve while the vacuum process was still going on. The water was allowed to flow until the level was beyond the samples. Then, the samples were vacuumed for another 1 hour. Then, vacuum process was stop and the samples were leave in the desiccator for 18 hours which was soaking process. After 18 hours, the samples were taken out from water and the surfaces of samples were dried up till Saturated Surface Dry (SSD) condition. After that, the outer surfaces of samples were applied on clear silicone except for the cut surface in order to avoid leakage to be happened. Then, the samples that had been applied with clear silicone were placed on the cells and were subjected to a 60-V potential for 6 hours. One of the cells was filled with 3% NaCl solution while another cell was filled with 0.3N NaOH solution. After that, the amount of electrical current passing through the samples was measured and the total charge passed which its' unit in coulombs was used as an indicator of the resistance of the concrete against chloride penetration. The figure 3.15 shows the equipment sets used in RCPT. Figure 3.16 shows the samples were inserted into vacuum desiccator to air vacuum for 3 hours. Figure 3.17 shows the samples were air vacuum with present of water for 1 hour. The samples were applied with clear silicone as shown in figure 3.18. Figures 3.19, 3.20 and 3.21 show the setting up for Rapid Chloride Permeability Test.

Figure 3.15 Equipment Sets for RCPT

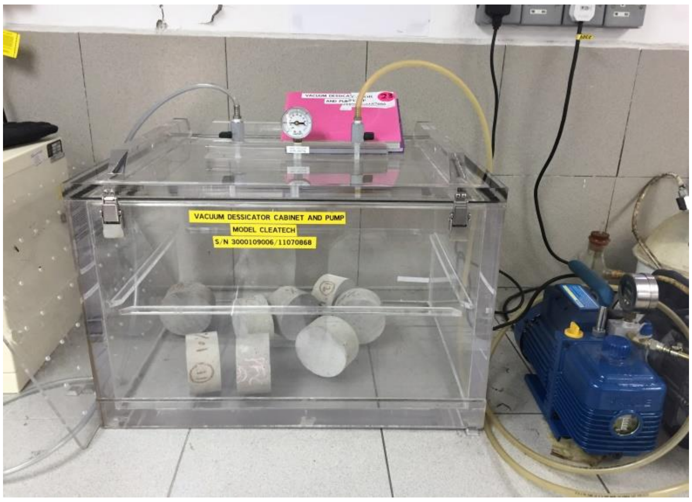


Figure 3.16 Air Vacuum of Samples

Figure 3.17 Air Vacuum of Samples with Present of Water

Figure 3.18 Samples after Applying Clear Silicone

Figure 3.19 Fitting Sample into Cell with 0.3N NaOH

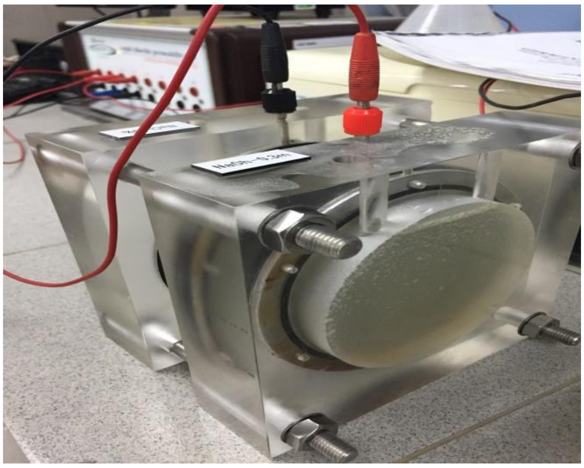


Figure 3.20 Setting up for RCPT

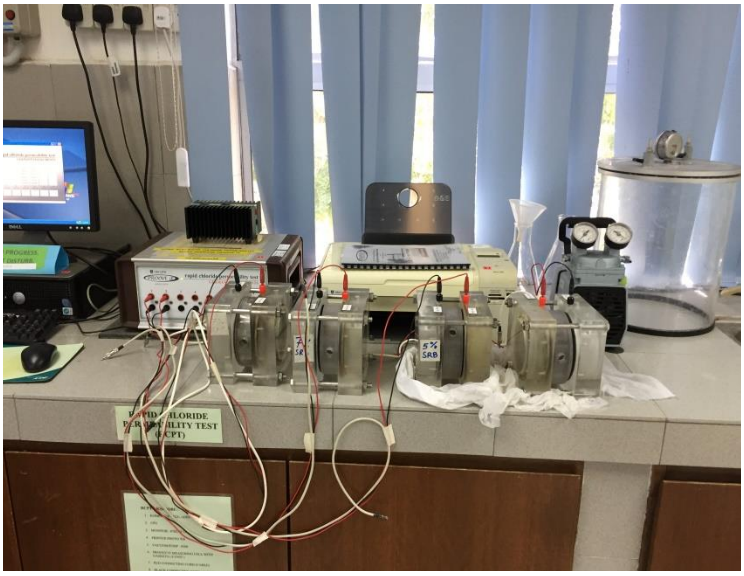


Figure 3.21 Rapid Chloride Permeability Test

3.5.3.1 Preparation of Specimen under Chloride Solution

The 5% chloride solution was prepared by using 50g of NaCl which is in solid form dilute with 50ml of distilled water, after that it was mixed with 950ml of distilled water. Figure 3.22 shows the solid form of sodium chloride is weighted and figure 3.23 shows the distilled water being used to create sodium chloride solution. 50 grams of NaCl is mixed with 50ml of distilled water to get 5% sodium chloride solution as shown in figure 3.24. Figure 3.25 shows the specimens were immersing in sodium chloride solution and figure 3.26 shows the weight of specimen was measured.

Figure 3.22 Sodium Chloride

Figure 3.23 Distilled Water

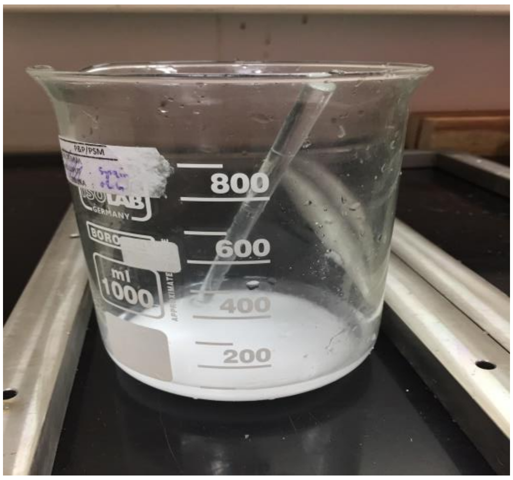


Figure 3.24 50g NaCl with 50ml Distilled Water

Figure 3.25 Specimens immersing in Sodium Chloride Solution

Figure 3.26 Weighting the Specimen

CHAPTER 4

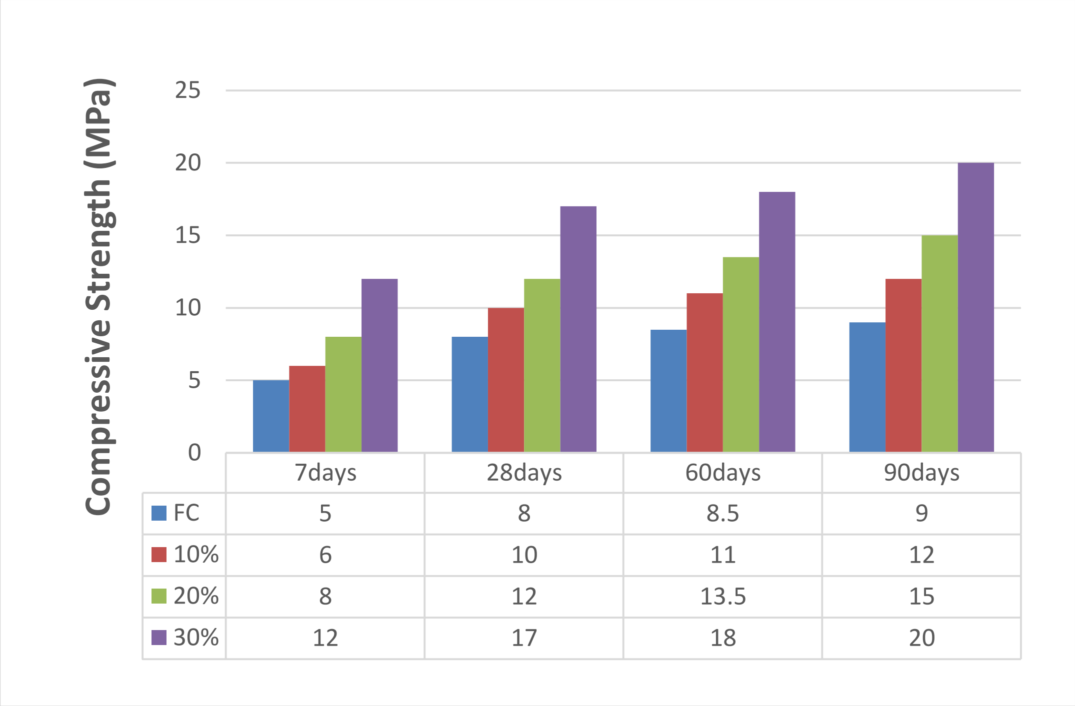
RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter presents the results from the experimental study. All the data has been analysed and discussed based on the aims of this study.

4.2 COMPRESSIVE STRENGTH UNDER WATER CURING

Figure 4.1 shows the compressive strength of foamed concrete mixtures containing 0 to 30 % PSBE as partial cement replacement in water curing. It is showed that the compressive strength increased as the curing age increased from 7 to 90 days for all mixes. As compared to control mix FC, the compressive strength of foamed concrete mixtures containing PSBE was higher than control FC. In most mix, PFC 3 showed the highest compressive strength. From the graph, it is showed that the compressive strength at 28 days for FC and PFC3 was 8MPa and 17MPa respectively. The trend was similar where the compressive strength gradually increased from 60 to 90 days. It has proven that PSBE acts as a good pozzolanic material in the mixture that leads to increase the calcium silicate hydrate (CSH) and make it denser, thus compressive strength is greater. This due to the reaction between calcium hydroxide and silicon dioxide from PSBE, the product of this reaction is CSH Gel where CSH Gel in here acting as bonding agent between particles. It is well known that pozzolan in concrete contribute to compressive strength (Aprianti S, 2015).



	7days	28days	60days	90days
FC	5	8	8.5	9
10%	6	10	11	12
20%	8	12	13.5	15
30%	12	17	18	20

Figure 4.1 Compressive Strength of Foamed Concrete under Water Curing

4.3 PERCENTAGE OF STRENGTH LOSS

Figure 4.2 shows the compressive strength of foamed concrete mixtures containing 0 to 30 % PSBE as partial cement replacement under chloride environment. It is showed that the compressive strength increased as the curing age increased from 7 to 90 days for all mixes. As reported earlier, in most mix, PFC 3 showed the highest compressive strength. From the graph, it is showed that the compressive strength at 28 days for FC and PFC3 was 6.32MPa and 15.69MPa respectively. As compared to water curing, there is similar trend for the compressive strength gradually increased from 60 to 90 days. The compressive strength of foamed concrete is normally depend on density of concrete, water cement ratio, foam content, type of foam, curing method and content of cement (Sayadi, Tapia, Neitzert, & Clifton, 2016). Meanwhile, another study was concluding that compressive of foam concrete is most significantly affected by foam content. The study also stated that compressive strength of foamed concrete is greatly affected by foam agent type such as protein based foam agent (Amran et al., 2015). Foamed concrete will exhibit higher compressive strength when the density is high (Sayadi et al., 2016).

Figure 4.3 shows the percentage loss in strength of foamed concrete after immersed in Chloride environment. Foamed concrete in water curing had higher compressive strength as compared to those under chloride environment. Normally, the concrete will achieve appropriate settling hardening time and the prevent cracking that may lead to weaker concrete. The percentage loss in strength for all mixtures increases before fall linearly after 28 days. This is because the specimens immersed in chloride solution being reacted which corrodes the body of the specimens thus makes the strength decreased. As compared to control mix FC, the percentage loss in strength of foamed concrete mixtures containing PSBE was lower than control FC (Abalaka 2011). Overall, PFC 3 shows the lowest percentage loss in strength. From the graph, it is showed that percentage loss in strength for FC and PFC3 was 21% and 7.71% respectively for curing day of 28. It is indicates that the 30% PSBE produce the higher durability exposed to chloride environment.

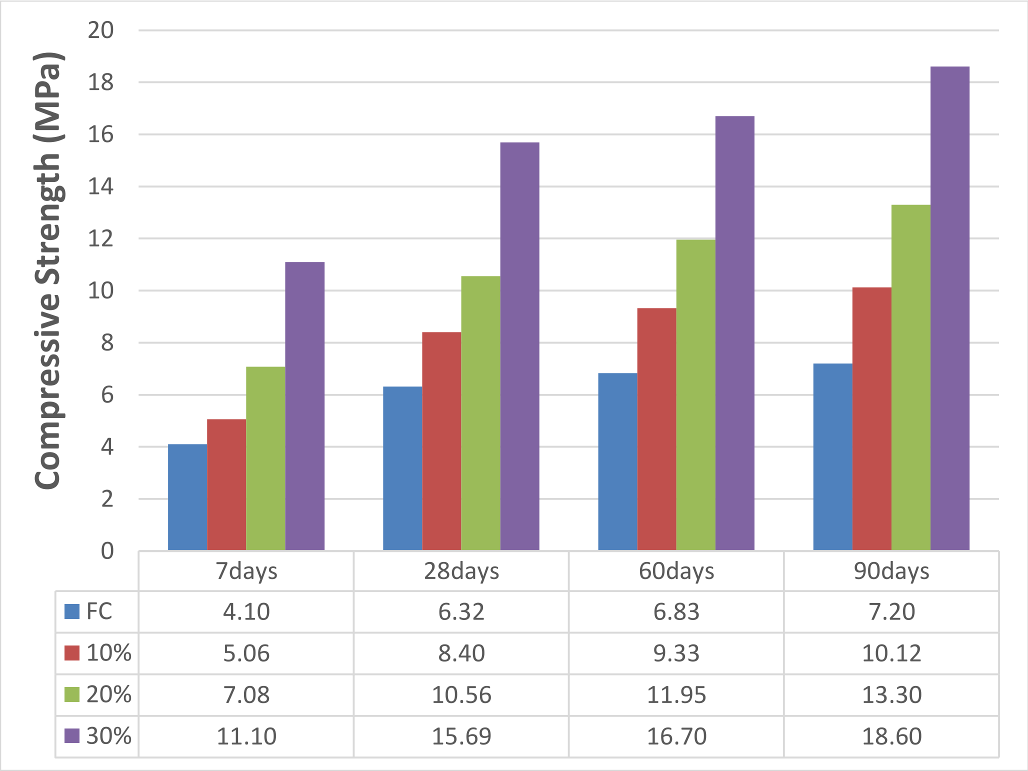
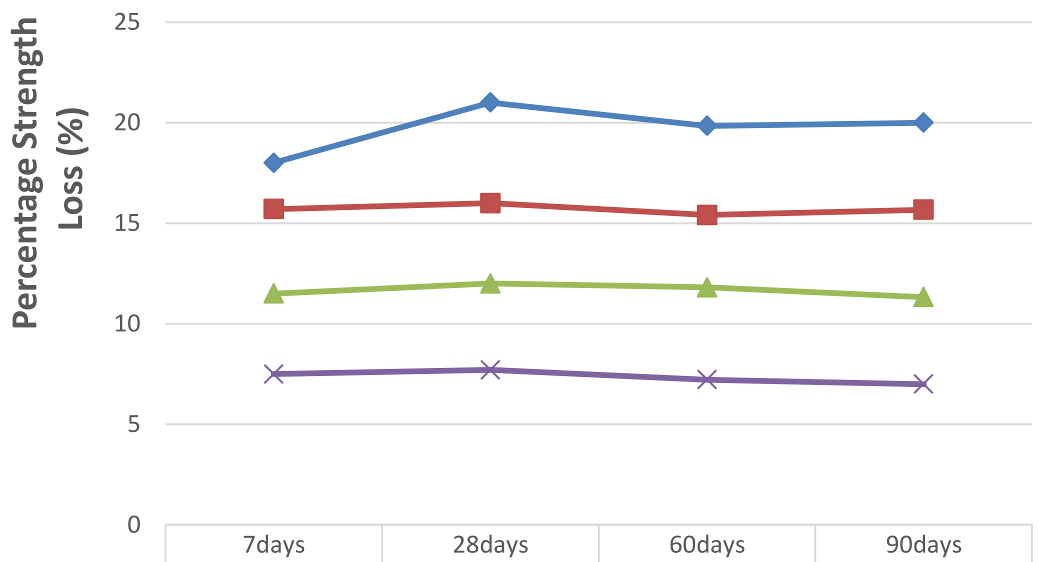


Figure 4.2 Compressive Strength of Foamed Concrete under Chloride Environment

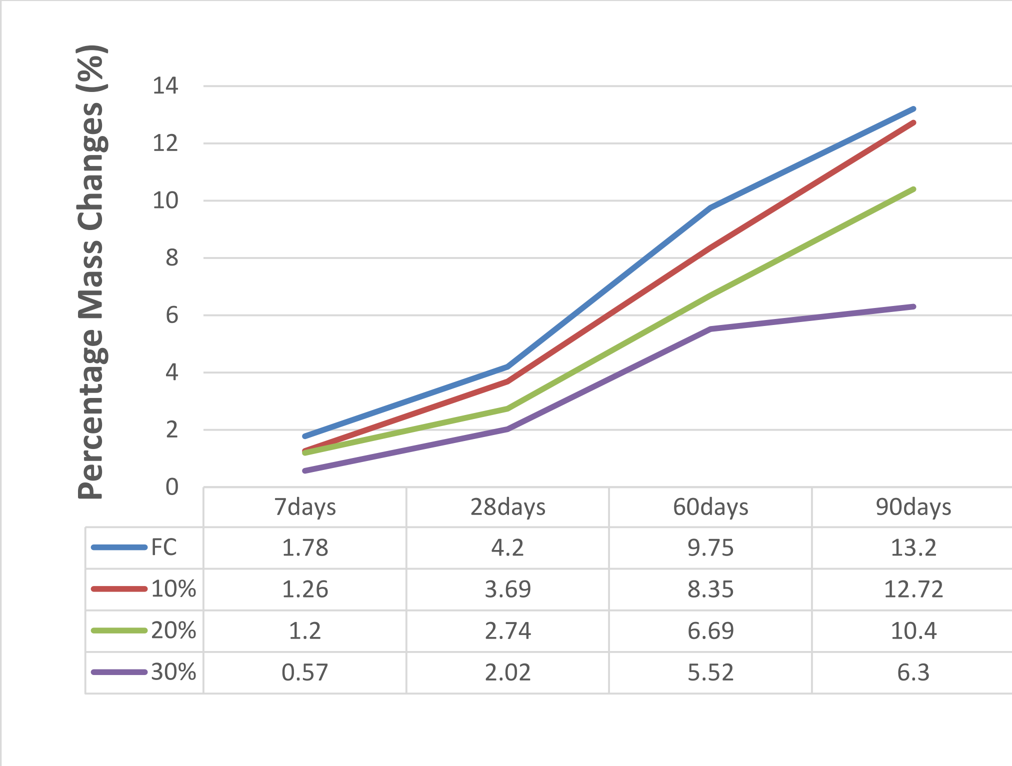


	7days	28days	60days	90days
FC	18	21	19.84	20
10%	15.7	16	15.41	15.67
20%	11.5	12	11.81	11.33
30%	7.5	7.71	7.22	7

Figure 4.3 Percentage of Strength Loss of Foamed Concrete under Chloride Environment

4.4 PERCENTAGE OF MASS LOSS

Figure 4.4 shows the percentage change in mass of foamed concrete mixtures containing 0 to 30 % PSBE as partial cement replacement exposed to Chloride environment for a period of 90 days. It is show that the percentage changes in mass increased as the curing age increased from day 7 to day 90 for exposure in sodium chloride solution (Karthika, 2016). As compared to control mix FC, the percentage change in mass of foamed concrete mixtures containing PSBE was lower than control FC. In most mix, PFC 3 showed the lowest percentage change in mass. From the graph, it is showed that percentage change in mass for FC and PFC3 with chloride curing of 90 days was 13.2% and 6.3% respectively. Hence, the 30% PSBE produce the higher durability exposed to chloride environment. It has proven that PSBE acts as a good pozzolanic material in the mixture that leads to decrease formation of ettringite due to low C3A content.



	7days	28days	60days	90days
FC	1.78	4.2	9.75	13.2
10%	1.26	3.69	8.35	12.72
20%	1.2	2.74	6.69	10.4
30%	0.57	2.02	5.52	6.3

Figure 4.4 Percentage of Mass Change of Foamed Concrete under Chloride Environment

4.5 PHYSICAL DETERIORATIONS

Figure 4.5, 4.6, 4.7 and 4.8 shows the deterioration for FC, 10%, 20% and 30% of PSBE specimen. The physical deteriorations of specimens were observed after immersing to 5% sodium chloride solution for 90 days. The physical of concrete cubes with 0, 10, 20 and 30% PSBE were compare before immersing to sodium chloride solution and after 90 days of immersion period. From observation, all mixtures seem to have non defect or deterioration on the surface after being immersed in chloride environment.

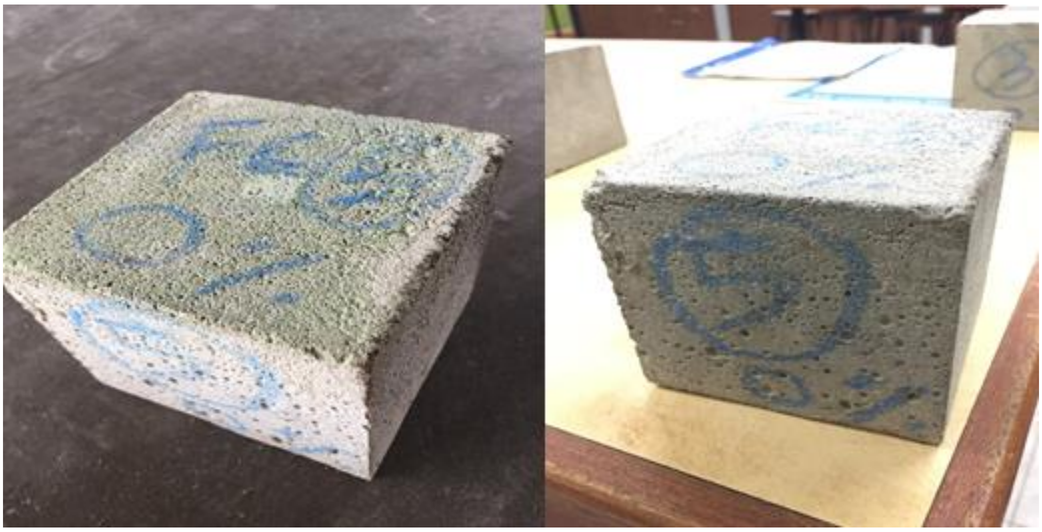


Figure 4.5 Deterioration before immersing in Sodium Chloride Solution and after 90days for Specimen with 0% PSBE

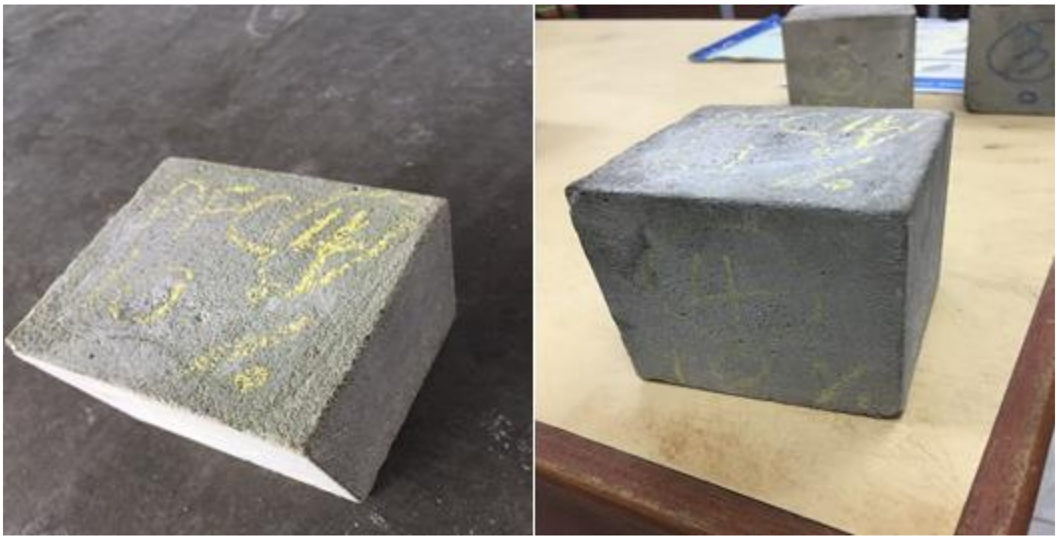


Figure 4.6 Deterioration before immersing in Sodium Chloride Solution and after 90days for Specimen with 10% PSBE

Figure 4.7 Deterioration before immersing in Sodium Chloride Solution and after 90days for Specimen with 20% PSBE

Figure 4.8 Deterioration before immersing in Sodium Chloride Solution and after 90days for Specimen with 30% PSBE

4.6 THERMAL CONDUCTIVITY TEST

Figure 4.9 shows the thermal conductivity of foamed concrete mixtures containing 0 to 30 % PSBE as partial cement replacement. The thermal insulation is good when the thermal conductivity is low. The graph indicated that FC has the lowest thermal conductivity and PFC 3 has the highest value. However, the thermal conductivity for PFC 3 has the most consistent of thermal insulation result for day 7 to

90 days. The thermal conductivity for FC was lowest that is 0.78 W/mK with water curing of 90 days. This was due to the dry density of FC is lower as compare to another foamed concrete mixes. The results indicated that the dry density is greatly affected the thermal insulation of lightweight foamed concrete (Alengaram et al., 2013). When dry density is high, the thermal conductivity is high. The thermal conductivity of foamed concrete with 0%, 10%, 20% and 30% PSBE are tabulated in tables 4.1, 4.2 and 4.3. The result showed that the thermal conductivity was increasing as the percentage of PSBE is increasing. For a good thermal insulation concrete, the thermal conductivity must be low. Incorporative of pozzolan affected the thermal conductivity as shown in tables 4.1, 4.2 and 4.3. This is due to the silica sand improved the bonding between material and the void was reduced, thus the thermal conductivity was affected. The degree of thermal insulation of foamed concrete also depends on the mixture composition such as mineral admixture and types of aggregates (Amran et al., 2015).

Table 4.1 Thermal Conductivity of Specimens with 7 days Water Curing

% PSBE	**Dry Density (kg/m^3)**	**Thermal Conductivity, k (W/mK)**
0	1198	0.86
10	1395	0.97
20	1589	1.02
30	1700	1.03

Table 4.2 Thermal Conductivity of Specimens with 28 days Water Curing

% PSBE	**Dry Density (kg/m^3)**	**Thermal Conductivity, k (W/mK)**
0	1233	0.78
10	1411	0.88
20	1599	1.01
30	1729	1.02

Table 4.3 Thermal Conductivity of Specimens with 60 days Water Curing

% PSBE	**Dry Density (kg/m^3)**	**Thermal Conductivity, k (W/mK)**
0	1265	0.73
10	1420	0.81
20	1606	0.95
30	1740	1.00

Table 4.4 Thermal Conductivity of Specimens with 90 days Water Curing

% PSBE	Dry Density (kg/m^3)	Thermal Conductivity, k (W/mK)
0	1299	0.72
10	1445	0.78
20	1615	0.87
30	1754	0.94

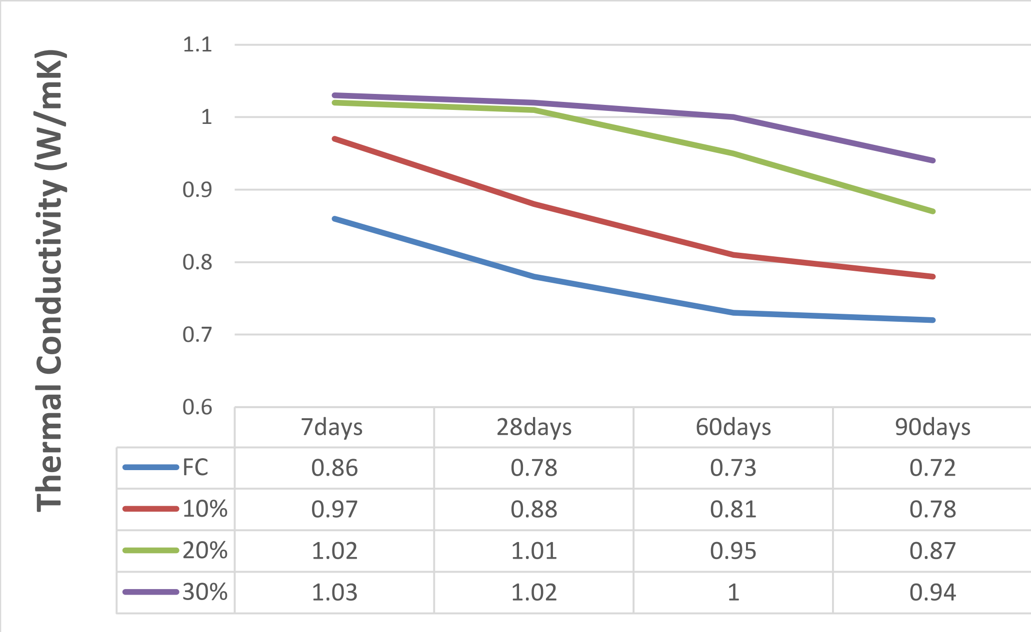


Figure 4.9 Thermal Conductivity of Foamed Concrete

4.7 RAPID CHLORIDE PERMEABILITY TEST

The RCPT was conducted only for FC and 30% of PSBE specimen. Figure 4.10 shows the charge in coulombs for FC and PFC3 from 7 to 90 days. The higher the charge passes through, the lower the resistance towards chloride attack. From the graph, it is showed that charge in coulombs for FC was higher than PFC3. The additional of pozzolan which is PSBE decrease the chloride ion permeability (Prinya Chindaprasirt, Rukzon, & Sirivivatnanon, 2008). According to charge passed ASTM C1202 in table 4.5, the FC was categorized in higher group based on its chloride ion permeability above 4000 coulombs from 7 to 90 days. Further, the PFC3 is categorized in moderate group since the coulombs were less than 4000 for curing day 7 to 90 days. Hence, the 30% PSBE produce the higher durability exposed to chloride environment.

For the foamed concrete with 0% PSBE as partial cement replace with water curing day of 7, 28, 60 and 90 days, the RCPT could not be run due to the overflowing of current through the specimens. It indicated that the Foamed concrete with 0% PSBE which is control mixed designed had low chloride resistance because the current is too easily passed through the samples. Thus, the results of FC were predicted by the equipment software which was around 14000 coulombs. There was a study showed that the water/binder ratio will affect RCPT value more for normal concrete as compared to those with high amount pozzolan (Sengul, Tasdemir, & Tasdemir, 2005).

Rapid chloride permeability test had been criticized by scientists due the charging pass through samples will affect all the ions but not just chloride ion only (Zych, 2014). The voltage which 60V is high and lead to rise in temperature, so the amount of charge pass through will be affected. This temperature change will lead to chemical and physical changes (Viljoen, 2014). Adding pozzolans in concrete are more effective than reducing the water cement ratio in order to increase the chloride resistance. The increase in chloride resistance by adding pozzolans is mainly due to the synergic effect of the fine pozzolans (P. Chindaprasirt, Rukzon, & Sirivivatnanon, 2008). This RCPT has no theoretical basis for the parameter using such as specimen thickness, specimen area, voltage applied and the period of testing. This is due to the changes in conditions of measurement during RCPT, thus the theoretical with the parameter is not likely to relate (Viljoen, 2014). However, RCPT is still widely used due to the short period of testing time.

Figure 4.10 Rapid Chloride Permeability Test of Foamed Concrete

Table 4.5 Chloride Ion Penetrability Based on Charge Passed according to ASTM

Coulombs	**Chloride Ion Permeability**	**Typical of**
>4000	High	High w/c-ratio
4000-2000	Moderate	0.4-0.5 w/c-ratio
2000-1000	Low	w/c-ratio <0.4
1000-100	Very low	Latex modif. Comcrete
<100	Negligible	Polymer concrete

CHAPTER 5

5.1 INTRODUCTION

This chapter concludes the research findings of this study from the experimental data. The integration of PSBE as partial cement replacement in foamed concrete has greatly influenced on the foamed concrete strength and durability. The findings exhibit that foamed concrete containing PSBE enhances the resistance of foamed concrete under chloride environment. However, there are still a few enhancements that can be recommended for future works for this study to get superior performance for structural application.

5.2 CONCLUSION

From the experimental data, it can be concluded that PSBE as partial cement replacement in foamed concrete enhanced the durability properties under chloride environment. The PSBE as partial cement replacement has greatly influenced on the foamed concrete strength and durability. The compressive strength of foamed concrete increased as increases in the percentage of PSBE as cement replacement. However, in most mixes the 30% of PSBE as cement replacement was performed better foamed concrete properties because the increases in the formation of secondary CSH gel instead of primer CSH Gel which leads to higher compressive strength compared to control FC. As compared to control foamed concrete, the percentage of strength loss and mass change decreases for mixtures that contain PSBE and thus make it more durable under chloride environment. Beside, rapid chloride ion penetration of PFC3 is categorized in moderate group since the coulombs were less than 4000 and the thermal conductivity is consistent.

5.3 RECOMMENDATION

Based on the study, PSBE is recommended to use as construction material because it enhanced the durability of concrete under chloride environment. The low density and high durability properties of concrete with PSBE showed that PSBE as partial cement replacement in foamed concrete will give better concrete performance. Somehow, further study should be conducted to enhance its properties as recommended by the following suggestions.

i. It is recommended to conduct a series of investigation on the effect of longer curing age and method on the properties of foamed concrete that containing PSBE.
ii. It is recommended to conduct the durability test against chloride under sea water environment.
iii. It is recommended to conduct a series of investigation on the resistant towards fire and carbonation effect.

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APPENDIX A
RESULT OF COMPRESSIVE TEST

Table A 1 Compressive Strength of Specimens under Water and Chloride Environment

Mixtures	Environment	Compressive Strength (MPa)			
		7 Days	28 Days	60 Days	90Days
Control (FC)	Water	5.0	8.0	8.5	9.0
	Chloride	4.1	6.3	6.8	7.0
10% PSBE	Water	6.0	10.0	11.0	12.0
	Chloride	5.1	8.4	9.3	10.1
20% PSBE	Water	8.0	12.0	13.5	15.0
	Chloride	7.1	10.6	12.0	13.3
30% PSBE	Water	12.0	17.0	18.0	20.0
	Chloride	11.1	15.7	16.7	18.6

Table A 2 Percentage Strength Loss of Foamed Concrete under Chloride Environment

Mixtures	Percentage of Strength Loss (%)			
	7 Days	28 Days	60 Days	90 Days
Control (FC)	18.0	21.0	19.8	20.0
10% PSBE	15.7	16.0	15.4	15.7
20% PSBE	11.5	12.0	11.8	11.3
30% PSBE	7.5	7.7	7.2	7.0

APPENDIX B
RESULT OF MASS CHANGE

Table B 1 Percentage of Mass Change of Foamed Concrete under Chloride Environment

Week	Mass Change (g)							
	Control (FC)		10% PSBE		20% PSBE		30% PSBE	
	Water	Chloride	Water	Chloride	Water	Chloride	Water	Chloride
1	1198	1219	1395	1413	1589	1608	1700	1710
2	1210	1241	1400	1429	1592	1620	1710	1728
3	1221	1263	1406	1446	1596	1631	1710	1746
4	1233	1285	1411	1463	1599	1643	1729	1764
5	1241	1311	1413	1482	1601	1660	1732	1782
6	1249	1337	1416	1501	1603	1678	1735	1800
7	1257	1362	1418	1520	1604	1696	1737	1818
8	1265	1388	1420	1539	1606	1713	1740	1836
9	1272	1405	1425	1557	1608	1727	1743	1842
10	1279	1421	1430	1575	1610	1741	1746	1847
11	1285	1438	1435	1593	1611	1755	1748	1853
12	1292	1454	1440	1611	1613	1769	1751	1859
13	1299	1471	1445	1629	1615	1783	1754	1865

APPENDIX C
RESULT OF THERMAL CONDUCTIVITY TEST

Table C 1 Thermal Conductivity Values for Control Foamed Concrete after 7 Days of Water Curing

Hours	**Heat Conduction (J/s) or (W)**	**Hot Surface temp (K)**	**Cold Surface temp (K)**	**Avg temp**	**Area, A (m^2)**	**Thickness, H (m)**	**Thermal Conductivity, k (W/mk)**
1	1.02	39.4	31.8	7.6	0.0079	0.05	0.86
2	0.90	39.4	32.7	6.7	0.0079	0.05	0.86
3	0.90	39.2	32.5	6.7	0.0079	0.05	0.86
4	0.94	39.1	32.1	7.0	0.0079	0.05	0.86
5	0.85	39.1	32.8	6.3	0.0079	0.05	0.86
6	0.86	39.2	32.8	6.4	0.0079	0.05	0.86
7	0.89	39.2	32.6	6.6	0.0079	0.05	0.86
8	0.84	39.1	32.9	6.2	0.0079	0.05	0.86
Avg	-	39.2	32.5	-	-	-	0.86

Table C 2 Thermal Conductivity Values for Foamed Concrete with 10% PSBE after 7 Days of Water Curing

Hours	**Heat Conduction (J/s) or (W)**	**Hot Surface temp (K)**	**Cold Surface temp (K)**	**Avg temp**	**Area, A (m^2)**	**Thickness, H (m)**	**Thermal Conductivity, k (W/mk)**
1	1.08	38.7	31.6	7.1	0.0079	0.05	0.97
2	0.93	38.8	32.7	6.1	0.0079	0.05	0.97
3	0.99	38.8	32.4	6.4	0.0079	0.05	0.97
4	0.93	38.9	32.8	6.1	0.0079	0.05	0.97
5	0.92	38.8	32.8	6.0	0.0079	0.05	0.97
6	0.90	38.7	32.8	5.9	0.0079	0.05	0.97
7	1.08	39.8	32.7	7.1	0.0079	0.05	0.97
8	0.93	38.8	32.7	6.1	0.0079	0.05	0.97
Avg	-	38.9	32.6	-	-	-	0.97

Table C 3 Thermal Conductivity Values for Foamed Concrete with 20% PSBE after 7 Days of Water Curing

Hours	**Heat Conduction (J/s) or (W)**	**Hot Surface temp (K)**	**Cold Surface temp (K)**	**Avg temp**	**Area, A (m^2)**	**Thickness, H (m)**	**Thermal Conductivity, k (W/mk)**
1	1.10	38.9	32.0	6.9	0.0079	0.05	1.02
2	0.97	38.9	32.8	6.1	0.0079	0.05	1.02
3	1.01	39.0	32.7	6.3	0.0079	0.05	1.02
4	0.99	39.0	32.8	6.2	0.0079	0.05	1.02
5	0.99	39.0	32.8	6.2	0.0079	0.05	1.02
6	1.01	39.1	32.8	6.3	0.0079	0.05	1.02
7	1.04	39.2	32.7	6.5	0.0079	0.05	1.02
8	1.02	39.1	32.7	6.4	0.0079	0.05	1.02
Avg	-	39.0	32.7	-	-	-	1.02

Table C 4 Thermal Conductivity Values for Foamed Concrete with 30% PSBE after 7 Days of Water Curing

Hours	**Heat Conduction (J/s) or (W)**	**Hot Surface temp (K)**	**Cold Surface temp (K)**	**Avg temp**	**Area, A (m^2)**	**Thickness, H (m)**	**Thermal Conductivity, k (W/mk)**
1	1.11	39.6	32.7	6.9	0.0079	0.05	1.03
2	1.00	39.0	32.8	6.2	0.0079	0.05	1.03
3	1.03	39.2	32.8	6.4	0.0079	0.05	1.03
4	1.03	39.2	32.8	6.4	0.0079	0.05	1.03
5	1.02	39.1	32.8	6.3	0.0079	0.05	1.03
6	1.00	39.1	32.9	6.2	0.0079	0.05	1.03
7	1.02	39.2	32.9	6.3	0.0079	0.05	1.03
8	0.98	39.0	32.9	6.1	0.0079	0.05	1.03
Avg	-	39.2	32.8	-	-	-	1.03

Table C 5 Thermal Conductivity Values for Control Foamed Concrete after 28 Days of Water Curing

Hours	Heat Conduction (J/s) or (W)	Hot Surface temp (K)	Cold Surface temp (K)	Avg temp	Area, A (m^2)	Thickness, H (m)	Thermal Conductivity, k (W/mk)
1	0.84	39.2	32.3	6.9	0.0079	0.05	0.78
2	0.77	39.0	32.7	6.3	0.0079	0.05	0.78
3	0.83	39.2	32.4	6.8	0.0079	0.05	0.78
4	0.77	39.1	32.8	6.3	0.0079	0.05	0.78
5	0.77	39.1	32.8	6.3	0.0079	0.05	0.78
6	0.76	39.0	32.8	6.2	0.0079	0.05	0.78
7	0.81	39.3	32.7	6.6	0.0079	0.05	0.78
8	0.78	39.1	32.7	6.4	0.0079	0.05	0.78
Avg	-	39.1	32.7	-	-	-	0.78

Table C 6 Thermal Conductivity Values for Foamed Concrete with 10% PSBE after 28 Days of Water Curing

Hours	Heat Conduction (J/s) or (W)	Hot Surface temp (K)	Cold Surface temp (K)	Avg temp	Area, A (m^2)	Thickness, H (m)	Thermal Conductivity, k (W/mk)
1	0.97	38.7	31.7	7.0	0.0079	0.05	0.88
2	0.99	38.9	31.8	7.1	0.0079	0.05	0.88
3	0.99	38.9	31.8	7.1	0.0079	0.05	0.88
4	0.96	38.9	32.0	6.9	0.0079	0.05	0.88
5	0.92	38.8	32.2	6.6	0.0079	0.05	0.88
6	0.93	38.9	32.2	6.7	0.0079	0.05	0.88
7	0.92	38.9	32.3	6.6	0.0079	0.05	0.88
8	0.89	39.1	32.7	6.4	0.0079	0.05	0.88
Avg	-	38.9	32.1	-	-	-	0.88

Table C 7 Thermal Conductivity Values for Foamed Concrete with 20% PSBE after 28 Days of Water Curing

Hours	**Heat Conduction (J/s) or (W)**	**Hot Surface temp (K)**	**Cold Surface temp (K)**	**Avg temp**	**Area, A (m^2)**	**Thickness, H (m)**	**Thermal Conductivity, k (W/mk)**
1	0.95	38.8	32.8	6.0	0.0079	0.05	1.01
2	0.90	38.9	33.2	5.7	0.0079	0.05	1.01
3	0.89	38.8	33.2	5.6	0.0079	0.05	1.01
4	0.90	38.8	33.1	5.7	0.0079	0.05	1.01
5	0.95	38.9	32.9	6.0	0.0079	0.05	1.01
6	0.98	38.9	32.7	6.2	0.0079	0.05	1.01
7	0.97	38.6	32.5	6.1	0.0079	0.05	1.01
8	0.98	38.5	32.3	6.2	0.0079	0.05	1.01
Avg	-	38.8	32.8	-	-	-	1.01

Table C 8 Thermal Conductivity Values for Foamed Concrete with 30% PSBE after 28 Days of Water Curing

Hours	**Heat Conduction (J/s) or (W)**	**Hot Surface temp (K)**	**Cold Surface temp (K)**	**Avg temp**	**Area, A (m^2)**	**Thickness, H (m)**	**Thermal Conductivity, k (W/mk)**
1	1.04	38.4	31.9	6.5	0.0079	0.05	1.02
2	1.01	38.6	32.3	6.3	0.0079	0.05	1.02
3	1.02	38.8	32.4	6.4	0.0079	0.05	1.02
4	1.09	39.0	32.2	6.8	0.0079	0.05	1.02
5	1.04	38.7	32.2	6.5	0.0079	0.05	1.02
6	1.01	38.5	32.2	6.3	0.0079	0.05	1.02
7	1.04	38.7	32.2	6.5	0.0079	0.05	1.02
8	1.02	38.5	32.1	6.4	0.0079	0.05	1.02
Avg	-	38.7	32.2	-	-	-	1.02

Table C 9 Thermal Conductivity Values for Control Foamed Concrete after 60 Days of Water Curing

Hours	Heat Conduction (J/s) or (W)	Hot Surface temp (K)	Cold Surface temp (K)	Avg temp	Area, A (m^2)	Thickness, H (m)	Thermal Conductivity, k (W/mk)
1	0.83	38.3	31.0	7.3	0.0079	0.05	0.73
2	0.82	38.3	31.1	7.2	0.0079	0.05	0.73
3	0.85	38.5	31.0	7.5	0.0079	0.05	0.73
4	0.84	38.4	31.0	7.4	0.0079	0.05	0.73
5	0.81	38.3	31.2	7.1	0.0079	0.05	0.73
6	0.85	38.6	31.1	7.5	0.0079	0.05	0.73
7	0.81	38.3	31.2	7.1	0.0079	0.05	0.73
8	0.82	38.4	31.2	7.2	0.0079	0.05	0.73
Avg	-	38.39	31.1	-	-	-	0.73

Table C 10 Thermal Conductivity Values for Foamed Concrete with 10% PSBE after 60 Days of Water Curing

Hours	Heat Conduction (J/s) or (W)	Hot Surface temp (K)	Cold Surface temp (K)	Avg temp	Area, A (m^2)	Thickness, H (m)	Thermal Conductivity, k (W/mk)
1	0.69	38.9	33.5	5.4	0.0079	0.05	0.81
2	0.66	39.0	33.8	5.2	0.0079	0.05	0.81
3	0.69	39.1	33.7	5.4	0.0079	0.05	0.81
4	0.72	39.4	33.8	5.6	0.0079	0.05	0.81
5	0.68	39.0	33.7	5.3	0.0079	0.05	0.81
6	0.69	38.9	33.5	5.4	0.0079	0.05	0.81
7	0.72	39.2	33.6	5.6	0.0079	0.05	0.81
8	0.69	39.0	33.6	5.4	0.0079	0.05	0.81
Avg	-	39.1	33.7	-	-	-	0.81

Table C 11 Thermal Conductivity Values for Foamed Concrete with 20% PSBE after 60 Days of Water Curing

Hours	**Heat Conduction (J/s) or (W)**	**Hot Surface temp (K)**	**Cold Surface temp (K)**	**Avg temp**	**Area, A (m^2)**	**Thickness, H (m)**	**Thermal Conductivity, k (W/mk)**
1	0.81	38.9	33.5	5.4	0.0079	0.05	0.95
2	0.78	38.9	33.7	5.2	0.0079	0.05	0.95
3	0.77	39.0	33.9	5.1	0.0079	0.05	0.95
4	0.80	39.1	33.8	5.3	0.0079	0.05	0.95
5	0.78	38.9	33.7	5.2	0.0079	0.05	0.95
6	0.81	38.9	33.5	5.4	0.0079	0.05	0.95
7	0.81	38.9	33.5	5.4	0.0079	0.05	0.95
8	0.84	39.1	33.5	5.6	0.0079	0.05	0.95
Avg	-	39.0	33.6	-	-	-	0.95

Table C 12 Thermal Conductivity Values for Foamed Concrete with 30% PSBE after 60 Days of Water Curing

Hours	**Heat Conduction (J/s) or (W)**	**Hot Surface temp (K)**	**Cold Surface temp (K)**	**Avg temp**	**Area, A (m^2)**	**Thickness, H (m)**	**Thermal Conductivity, k (W/mk)**
1	0.89	38.7	33.0	5.7	0.0079	0.05	1.00
2	0.89	38.7	33.2	5.5	0.0079	0.05	1.00
3	0.86	38.7	33.2	5.5	0.0079	0.05	1.00
4	0.91	38.9	33.1	5.8	0.0079	0.05	1.00
5	0.86	38.8	33.3	5.5	0.0079	0.05	1.00
6	0.91	39.0	33.2	5.8	0.0079	0.05	1.00
7	0.88	38.7	33.1	5.6	0.0079	0.05	1.00
8	0.94	38.8	32.8	6.0	0.0079	0.05	1.00
Avg	-	38.8	33.1	-	-	-	1.00

Table C 13 Thermal Conductivity Values for Control Foamed Concrete after 90 Days of Water Curing

Hours	Heat Conduction (J/s) or (W)	Hot Surface temp (K)	Cold Surface temp (K)	Avg temp	Area, A (m^2)	Thickness, H (m)	Thermal Conductivity, k (W/mk)
1	0.63	39.3	33.7	5.6	0.0079	0.05	0.72
2	0.61	39.1	33.7	5.4	0.0079	0.05	0.72
3	0.65	39.3	33.5	5.8	0.0079	0.05	0.72
4	0.62	38.9	33.4	5.5	0.0079	0.05	0.72
5	0.68	39.1	33.1	6.0	0.0079	0.05	0.72
6	0.66	39.1	33.2	5.9	0.0079	0.05	0.72
7	0.65	39.1	33.3	5.8	0.0079	0.05	0.72
8	0.65	39.0	33.2	5.8	0.0079	0.05	0.72
Avg	-	39.1	33.4	-	-	-	0.72

Table C 14 Thermal Conductivity Values for Foamed Concrete with 10% PSBE after 90 Days of Water Curing

Hours	Heat Conduction (J/s) or (W)	Hot Surface temp (K)	Cold Surface temp (K)	Avg temp	Area, A (m^2)	Thickness, H (m)	Thermal Conductivity, k (W/mk)
1	0.57	38.7	34.0	4.7	0.0079	0.05	0.78
2	0.56	38.6	34.0	4.6	0.0079	0.05	0.78
3	0.55	38.7	34.2	4.5	0.0079	0.05	0.78
4	0.55	38.7	34.2	4.5	0.0079	0.05	0.78
5	0.59	39.0	34.2	4.8	0.0079	0.05	0.78
6	0.59	38.7	33.9	4.8	0.0079	0.05	0.78
7	0.59	38.6	33.8	4.8	0.0079	0.05	0.78
8	0.59	38.6	33.8	4.8	0.0079	0.05	0.78
Avg	-	38.7	34.0	-	-	-	0.78

Table C 15 Thermal Conductivity Values for Foamed Concrete with 20% PSBE after 90 Days of Water Curing

Hours	Heat Conduction (J/s) or (W)	Hot Surface temp (K)	Cold Surface temp (K)	Avg temp	Area, A (m^2)	Thickness, H (m)	Thermal Conductivity, k (W/mk)
1	0.78	38.7	33.0	5.7	0.0079	0.05	0.87
2	0.72	38.7	33.4	5.3	0.0079	0.05	0.87
3	0.75	38.9	33.4	5.5	0.0079	0.05	0.87
4	0.74	39.0	33.6	5.4	0.0079	0.05	0.87
5	0.72	38.8	33.5	5.3	0.0079	0.05	0.87
6	0.74	38.9	33.5	5.4	0.0079	0.05	0.87
7	0.71	38.7	33.5	5.2	0.0079	0.05	0.87
8	0.72	38.8	33.5	5.3	0.0079	0.05	0.87
Avg	-	38.8	33.4	-	-	-	0.87

Table C 16 Thermal Conductivity Values for Foamed Concrete with 30% PSBE after 90 Days of Water Curing

Hours	Heat Conduction (J/s) or (W)	Hot Surface temp (K)	Cold Surface temp (K)	Avg temp	Area, A (m^2)	Thickness, H (m)	Thermal Conductivity, k (W/mk)
1	0.78	38.6	33.3	5.3	0.0079	0.05	0.94
2	0.72	38.8	33.9	4.9	0.0079	0.05	0.94
3	0.69	39.1	34.4	4.7	0.0079	0.05	0.94
4	0.68	39.2	34.6	4.6	0.0079	0.05	0.94
5	0.68	39.1	34.5	4.6	0.0079	0.05	0.94
6	0.69	39.0	34.3	4.7	0.0079	0.05	0.94
7	0.69	39.2	34.5	4.7	0.0079	0.05	0.94
8	0.66	38.9	34.4	4.5	0.0079	0.05	0.94
Avg	-	39.0	34.2	-	-	-	0.94

APPENDIX D
RESULT OF RAPID CHLORIDE PERMEABILITY TEST

PROOVE it

ASTM C 1202-97

Fakulti Kejuruteraan Awam
Faculty of Civil Engineering

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GERMANN INSTRUMENTS

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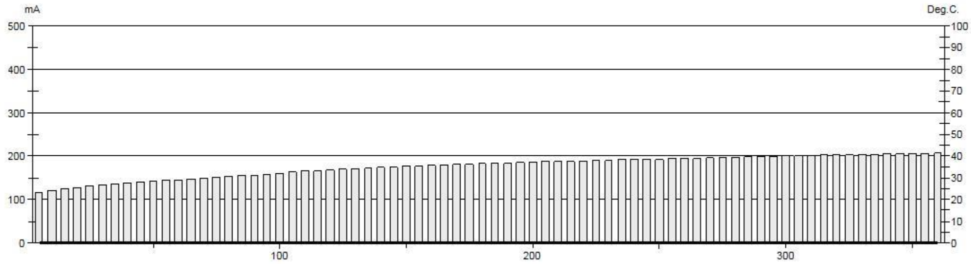
Test report

Voltage Used:	60
Testing time:	06:00 hour
Charge passed:	3799
Adjusted Charge passed:	3429
Permeability class:	Moderate
Instrument number:	074104
Channel number:	1
Report date:	2/16/2017
Testing by:	TING QIANG CHAO
Reference:	28th day with 30%
Sample diameter:	100
Comment:	---



Time	°C	mA	Time	°C	mA	Time	°C	mA	Time	°C	mA
00:05	0	116.2	01:35	0	159.5	03:05	0	182.9	04:35	0	196.3
00:10	0	121.2	01:40	0	161.0	03:10	0	183.2	04:40	0	197.1
00:15	0	125.1	01:45	0	162.7	03:15	0	185.2	04:45	0	197.6
00:20	0	128.2	01:50	0	164.3	03:20	0	186.3	04:50	0	198.2
00:25	0	131.0	01:55	0	165.9	03:25	0	187.1	04:55	0	199.4
00:30	0	133.5	02:00	0	167.4	03:30	0	187.9	05:00	0	200.4
00:35	0	135.8	02:05	0	169.1	03:35	0	188.4	05:05	0	201.2
00:40	0	138.0	02:10	0	170.3	03:40	0	188.6	05:10	0	201.8
00:45	0	140.1	02:15	0	171.6	03:45	0	189.4	05:15	0	202.2
00:50	0	142.1	02:20	0	173.0	03:50	0	190.1	05:20	0	202.7
00:55	0	144.2	02:25	0	174.4	03:55	0	191.0	05:25	0	203.3
01:00	0	146.1	02:30	0	175.6	04:00	0	192.1	05:30	0	203.8
01:05	0	148.1	02:35	0	176.9	04:05	0	192.8	05:35	0	203.9
01:10	0	149.9	02:40	0	177.9	04:10	0	193.0	05:40	0	204.6
01:15	0	151.8	02:45	0	178.8	04:15	0	193.7	05:45	0	204.8
01:20	0	153.6	02:50	0	180.0	04:20	0	194.7	05:50	0	205.5
01:25	0	155.5	02:55	0	181.1	04:25	0	195.3	05:55	0	206.1
01:30	0	157.3	03:00	0	182.0	04:30	0	195.8	06:00	0	206.8