PERFORMANCE OF ECO PROCESS POZZOLAN FOAMED CONCRETE AS CEMENT REPLACEMENT

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ABSTRACT

Nowadays with the demand of construction and advancement of technology, industrial waste becomes potential innovation product for construction materials. Eco Process Pozzolan Foamed Concrete (EPPFC) is the mixing of cement paste with preformed foam which EPP is used as replacement for cement. This study is to investigate the optimum EPP as cement replacement through a series of experimental for five types of mixture of foamed concrete namely FC with 100% of OPC as control sample and 20%, 25%, 30%, 35%, 40% EPPFC. All the specimens have been prepared and tested to determine the compressive strength, workability, porosity and water absorption. From the laboratory test conducted, it can be concluded that the replacement of Eco Process Pozzolan (EPP) that less than 30% will give out a better performance properties compared to control foamed concrete. The replacement of cement with EPP in the concrete mixture leads to the reduce of landfill, with reduction of cement usage there would be less release of carbon dioxide (CO_2) into the atmosphere in equivalent proportion. The usage of EPP will also reduce the cost of the project. It is predictable that the foamed concrete with certain percentage of EPP performs better than the control specimens. In future, EPP can be recommended to be used as a new mineral ad mixture for greener construction materials.

ABSTRAK

Pada masa kini dengan permintaan pembinaan dan kemajuan teknologi, sisa industri menjadi produk inovasi yang berpotensi untuk bahan-bahan pembinaan. Eco Process Pozzolan Concrete Foamed (EPPFC) adalah mencampurkan adunan simen dengan buih terbentuk terlebih dahulu yang EPP digunakan sebagai pengganti simen. Kajian ini bertujuan untuk mengkaji nilai optimum EPP sebagai pengganti simen melalui satu siri eksperimen bagi lima jenis campuran konkrit berbusa iaitu FC dengan 100% daripada OPC sebagai sampel kawalan dan 20%, 25%, 30%, 35%, 40% EPPFC . Semua spesimen telah disediakan dan diuji untuk menentukan kekuatan, kebolehkerjaan, keliangan dan air penyerapan mampatan. Daripada ujian makmal yang dijalankan, dapat disimpulkan bahawa penggantian Eco Process Pozzolan (EPP) yang kurang daripada 30% akan memberikan ciri-ciri prestasi yang lebih baik berbanding dengan sampel kawalan konkrit foamed. Penggantian simen dengan EPP di dalam campuran konkrit membawa kepada mengurangkan tapak pelupusan, dengan pengurangan penggunaan simen akan dapat mengurangkan pembebasan karbon dioksida (CO_2) ke atmosfera dalam nisbah setara. Penggunaan EPP juga akan mengurangkan kos projek. Ia dapat diramalkan bahawa konkrit berbusa dengan peratusan tertentu daripada EPP memberi kesan yang lebih baik daripada spesimen kawalan. Pada masa akan datang, EPP boleh disyorkan untuk digunakan sebagai campuran mineral baru untuk bahan-bahan pembinaan hijau.

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LIST OF ABBREVIATIONS

EPPFC	Eco Process Pozzolan Foamed Concrete
EPP	Eco Process Pozzolan
FC	Foamed Concrete
M	Mortar
OPC	Ordinary Portland Cement
ASTM	American Society for Testing and Materials
FKASA	Fakulti Kejuruteraan Awam dan Sumber Alam
UTM	Universal Testing Machine
UMP	Universiti Malaysia Pahang
US	United State
AAC	Autoclaved Aerated Concrete
AA	Alkali Activation
GGBS	Ground Granular
FA_{fine}	Fly Ash Fine Aggregates
w/c	Water/Cement
s/c	Sand/Cement
Msat	Saturated Mass
Mdry	Mass of Oven Dry Density
Mw	Water/buoyancy mass
m_b	Mass when the material absorbs water to saturation
m_g	Mass when the material is dry
W_m	Specific Absorption of Quality
MgO	Magnesium Oxide
SO_3	Sulphur Trioxide
BET	Blaine Surface Area
CO_2	Carbon Dioxide
CH	Calcium hydroxide
CSH	Calcium silicate hydrate
C_3S	Tricalcium silicate

CaO	Calcium Oxide
SiO_2	Silicon Dioxide
Al_2O_3	Aluminium Trioxide
Fe_2O_3	Ferric Oxide
MWh	MegaWatt
kg/m^3	Kilogram per meter cube
Mpa	Mega Pascal
lbs	Pound
pints	Unit of volume
L	Litre
mm	Milimeter
h	Hour
cm^2/g	Centimeter square per gram
kN	kilo Newton
kN/s	kilo Newton per second
kPa	kilo Pascal
C^o	Degree Celcius
%	Percentage

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Cement is an important construction ingredient around the world, and as a result, cement production is a significant source of global carbon dioxide (CO_2) emissions, making up approximately 2.4 percent of global CO_2 emissions from industrial and energy sources (Gibbs, Soyka, & Conneely, 2000). Nowadays, construction's company seek for cement that are more lighter, durable, practical, economic and environmental sustainable materials to meets their requirement on construction. Foamed concrete also known as less density cement is the combination of cement paste and preformed foams that causes the foamed concrete to be lighter than normal concrete. Eco process pozzolan foamed concrete (EPPFC) is the mixing of cement paste with pre-foamed foam which EPP is used as cement replacement for cement. Originally, EPP is a process from spent bleaching earth which is a solid waste originating from edible oil refinery process which generates high quantities of waste due to refining process of crude edible oil. The replacement of cement with EPP in the concrete mixture leads to the landfill, with reduction of cement usage there would be less release of carbon dioxide (CO_2) into the atmosphere in equivalent proportion. The usage of EPP will also reduce the cost of the project.

Eco Process Pozzolan Foamed Concrete (EPPFC) is the mixing of cement paste with preformed foam which EPP is used as replacement for cement. This study is to investigate the optimum EPP as cement replacement through a series of experimental for five types of mixture of foamed concrete namely FC with 100% of OPC as control sample and 20%, 25%, 30%, 35%, 40% EPPFC. All the specimens have been prepared and tested to determine the compressive strength, workability, porosity and water absorption.

1.2 PROBLEM STATEMENT

Foam concrete is a lightweight material consisting of Portland cement paste or cement filler matrix (mortar) with a homogeneous void or pore structure created by introducing air in the form of small bubbles. High air contents results in lower densities, higher porosities and lower strength (Kearsley & Wainwright, 2001). In view of the importance of saving of energy and conservation of resources, it is essential to find a functional substitute of cement in manufacture of FC (Ji, He, Zhang, Liu, & Wang, 2015). Cement is one of the very important raw materials in construction industry. However, cement factory emitted Carbon Dioxide (CO_2) during the production to the surrounding. The higher rate of the construction had caused the increase rate of demand for production of cement in factory. As a result, cement production is a significant source of global CO_2 emissions, making up approximately 2.4% of global CO2 emissions from industrial and energy sources (Gibbs et al., 2000). The amount of CO2 emitted to surrounding is based on the amount tonnage production in factory. The production of one ton of cement production consumes about 1.6MWh energy and discharge about one tonne of carbon dioxide into the atmosphere (Narayanan & Ramamurthy, 2000). Malaysia has produced 19,500 thousands metric tons of cement in 2010 (Indexmundi,2013). Hence, Malaysia had produced 17.55 million of CO_2 to the atmosphere. The emission of CO_2 will cause to serious greenhouse effect to the global.

1.3 SIGNIFICANT OF STUDY

This significant of this study is to learn about the performance of EPP foam concrete in mechanical properties. Besides that, this study was using EPP as the waste material is becoming useful and makes benefits to the construction industry for better and greener environment.

1.4 OBJECTIVE OF STUDY

The goal of this study is to investigate the performance of EPP in foamed concrete properties as cement replacement. The specific objectives of this study are:

a) To determine the workability and fresh density of foamed concrete
b) To determine the oven dry density and compressive strength of foamed concrete.
c) To determine the water absorption and porosity of foamed concrete

1.5 SCOPE OF STUDY

The goal of study is to investigate the performance of EPP in foamed concrete properties as cement replacement. It is focused on the influence of EPP on the workability, density, compressive strength, water absorption and porosity due to water and air curing at 7,14, and 28 days. The study is divided into four main phases as follows:

i. Phase 1 is to prepare Portland cement, silica sand, preform foamed and Eco Process Pozzolan (EPP) and sieve analysis.
ii. Phase 2 is to prepare EPP for the cement replacement in concrete mixtures. The percentage of EPP used is based on 5 different proportion.
iii. Phase 3 is to prepare and analyse the slurry and EPP mixtures workability by using flow table test
iv. Phase 4 is to test the performance of EPP according to density, compressive test, porosity test and water absorption test.

All the material and specimens preparation are conducted based on standard code of practice design requirement of ASTM at FKASA laboratory, Universiti Malaysia Pahang, Gambang Malaysia.

CHAPTER 2

LITERATURE RIVIEW

2.1 INTRODUCTION

This chapter discussed the previous study of cement replacement in foamed concrete. It is important to understand the foamed concrete in term of its material, production and properties. Figure 2.1 shows the literature review process of this study.

2.2 FOAMED CONCRETE

2.2.1 Definition and evolution

Foam concrete, also known as foamed concrete, foamcrete, cellular lightweight concrete or reduced density concrete, is defined as a cement based slurry, with a minimum of 20% (per volume) foam entrained into the plastic mortar. As mostly no coarse aggregate is used for production of foam concrete the correct term would be called mortar instead of concrete. Sometimes it may be called as “Foamed Cement” or “Foam Cement” because of mixture of only Cement & Foam without any fine aggregate. The density of foam concrete usually varies from 400 kg/m^3 to 1600 kg/ m^3. The density is normally controlled by substituting fully or part of the fine aggregate with foam. Cellular Concrete was first developed in Stockholm, Sweden in the early 1900’s. The original material was known as “gas concrete” to be used in producing heat-insulated building materials. This led to the development of related lightweight concrete which are now known as cellular concrete, foamed concrete, aerated concrete and autoclaved cellular concrete. (contributors, 2015)

After the Second World War, this technology quickly spread to different parts of the world, mostly Europe and the Soviet Union. The applications were for economical large-size structural panel units. These were used in site reconstruction and low-rise structures. It wasn’t till the late 1950’s when this was introduced to the US as foamed or cellular concrete. The applications were for floor, roof and wall units. Having low compression strengths, it limited this product to fills and insulation only. Following this research, new admixtures were developed in the late 1970s and early 80s, which led to the commercial use of foamed concrete in construction projects. Initially, it was used in the Netherlands for filling voids and for ground stabilisation. Further research carried out in the Netherlands helped bring about the more widespread use of foam concrete as a building material. (Lcc, 2003)

2.2.2 Application of Foam Concrete in Construction

Foamed concrete is a versatile material. It is possible to produce with pigments, accelerators, retarders, fibres, fast setting cements, pozzolanic cements, recycled fillers and rheology controllers to tailor the workability, strength development rate and other properties to suit a wide range of applications. Its traditional use is for trench reinstatements, as it is self-compacting (eliminating the ‘white finger’ vibration exposure problem of compacting conventional granular fill), does not settle and its load-spreading characteristics prevent direct transmission of axial loads to services. Its ability to flow easily under its self-weight has led to its use in void filling, including old sewerage pipes, wells, cellars and basements of old buildings, storage tanks, tunnels and subways. Because of its good thermal properties, foamed concrete has been used as an insulating material on roofs, in housing foundations and floors. Its inherent fire resistance has also been exploited in a wide range of uses, such as tilt-up firewalls, vaults etc. Foamed concrete has also been used successfully in bridge foundations, instead of other backfill materials or to provide soil stability on embankment slopes and enhance its bearing capacity with cast-in-place foamed concrete ‘piles’. Other applications include precast elements, in raft foundations of houses, as a foundation-layer for sports fields and athletic tracks, for annulus grouting of segmental tunnels, backfilling the voids behind tunnel linings, providing base for storage tanks or as blinding material. Sources by (Society, n.d.)

2.3 Constituents material of Foamed concrete

2.3.1 Cement

Cement play important role as binder for the sand to form foamed concrete. In concrete, cement bind with water and turn harder by chemical reaction (Brocken & Nijland, 2004). Cement have place in the place which away from water because it very sensitive to water. Cement will turn harden once it near water (Davidson, 1977). According to (Kearsley & Wainwright, 2001) on their research, with used of rapid hardening Portland cement from Pretoria Portland Cement (PPC) the compressive strength of foamed concrete with densities of 1500 kg/m^3 increasing at an early stage (7 days) and showing no significant reduction in strength. This is because cement has low solubility and low diffusivity, hence, make the hydration processes more rapidly ("Significance of Tests and and Concrete-Making STP 169D," 2012).

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2.3.2 Sand

(Nambiar, Ramamurthy, & Asce, 2008) reported that with density of 1000kg/m^3 to 1800kg/m^3 for 0% to 100% Fly Ash as pulverized river sand replacement cause increase in surface area, thus necessitate higher water demand. When replacing sand with fly ash by mass, the consistency of the mix is reduced due to a higher fines content. So, an increase in the water–solids ratio is required with an increase in the fly ash replacement level in sand.

2.3.3 Water

The amount of water to be added to the mix depends upon the moisture content of the sand, but as an average figure, 40-45 litres (85-96 pints) of water is used for every 100 kilograms (222 lbs) of cement. Additional water is added as a content of the foam, thereby bringing the total water : cement ratio up to the order to 0.6. In general, when the amount of foam is increased, as for lighter densities, the amount of water can therefore be decreased. (Pacific, n.d.)

The w/c ratio should be kept as low as possible in order to avoid unnecessary shrinkage in the moulds, however, it should be remembered that, if the amount of water added to cement and sand in the first instance it too low, the necessary moisture to make a workable mix will be extracted from the foam when it is added, thereby destroying some of the foam which is naturally an expensive way of adding water to the mix. (Pacific, n.d.)

2.3.4 Foaming Agent

According to (Abdullah et al., 2012) from the research that has been conducted, foamed concrete is produced by using mortar or cement paste in which large volume of air are entrapped by using a foaming agent. There are various type of foaming agent that can be used to produce foamed concrete, including detergent, saponin, and hydrolysed proteins, such as keratin and similar materials. The prominent advantage of foamed concrete is its lightweight, which economises the design of supporting structures including the foundation and wall of lower floor. It also been reported by (Narayanan & Ramamurthy, 2000) that aluminium powder as foaming agent provides a high degree of thermal insulation and considerable savings in material due to the porous structure.

2.4 PRODUCTION OF FOAMED CONCRETE

Foamed concrete is a cementitious paste of neat cement or cement and fine sand with a multitude of micro/macroscopic discrete air cells uniformly distributed throughout the mixture to create a lightweight concrete. It is commonly manufactured by two different methods. Method A, consists of mixing a pre-formed foam [surfactant] or mix-foaming agents mixture into the cement and water slurry. As the concrete hardens, the bubbles disintegrate leaving air voids of similar sizes.

Method B, known as Autoclaved Aerated Concrete [AAC] consists of a mix of lime, sand, cement, water and an expansion agent. The bubble is made by adding expansion agents [aluminum powder or hydrogen peroxide] to the mix during the mixing process. This creates a chemical reaction that generates gas, either as hydrogen or as oxygen to form a gas-bubble structure within the concrete. High carbon ash, recycled aluminium waste and zeolite powders are additional mechanical structures suitable in the production of cellular lightweight concrete. (Lcc, 2003)

2.5 PROPERTIES OF FOAMED CONCRETE

2.5.1 Density

The density or more precisely, the volumetric mass density is a unit for weighing the weight of the foamed concrete. The density can be identify based on the fresh state and harden state for foamed concrete. As foam concrete cannot be subjected to compaction or vibration the foam concrete should have flow ability and self-compact ability. These two properties are evaluated in terms of consistency and stability of foam concrete.

There are relationship between fresh density and oven dry density of foamed concrete. From the previous study by (Memon, Arsalan, Khan, & Lo, 2012), it can be seen that, fresh and dry density decreases with the increase in the percentage of bentonite. The bentonite mixes has produced fresh state with 2482 kg/m^3. It is shows that oven dry density is 5% lesser than fresh density of foamed concrete for water curing. It has been observed that the oven dry density of foamed concrete decreased as bentonite increase in the mixture due to specific gravity of the cement which is higher than bentonite. Similar trend has been reported by (Memon et al., 2012) which for the concrete or mortar made with pozzolan materials has lower density than control specimen produced by 100 % of cement.

2.5.2 Workability

Water cement ratio controls workability of the fresh concrete. Generally, to measure the workability, slump test is used. Previous study on Pozzolan material (Yetgin & Çavdar, 2006) reported that with density of 1400 kg/m^3 , the workability of natural pozzolan increases as the natural pozzolan addition ratio increased. The workability of cement mortar containing Natural Pozzolan decreased as the increased percentage of Natural pozzolan in the mix. The result show with 35% of Natural Pozzolan mixtures have given the higher content of natural pozzolan mixture with workability of 210 mm flow diameter. From the result, it can be pointed out that the accretion of workability of mixture when Natural Pozzolan is increasing it may due to fineness of Natural Pozzolan compare to cement mortar. According to (Çolak, 2003) reported that small particle size and relatively higher surface area of pozzolan particles has less workability than 100% cement mixture.

2.5.3 Water Absorption

Absorption is usually measured by drying the specimen to constant mass, immersing it in water and measuring the increase in mass as a percentage of dry mass. Various procedures can be used like 24 h immersion in water, immersion till constant mass and vacuum saturation method resulting in widely different results. According to ASTM C642 (Astm:C642-13, 2013), water absorption is the test to determine the relative water absorption by capillary uptake characteristic of mortar. In ASTM C642, the water absorbed by an oven-dried specimens is measured after a 48 hours immersion or after such immersion followed by 5 hours in boiling water. The ration of the water absorbed to the dry weight is the absorption. Capillary absorption is not only affected by the w/c ratio but also by the paste content in the mix. As the paste content increases the absorption also increases and the effect is more pronounced for higher W/C ratios (Kolias & Georgiou, 2005).

According to (Ahmad, Barbhuiya, Elahi, & Iqbal, 2011) in his research on Bentonite, with 30% of bentonite, the water absorption decreased for mortar and then steadily increased at greater bentonite loadings. The demand of water increased with an increase in the bentonite content. Also stated by (Mirza et al., 2009) in research of Pozzolan, water absorption decreased with the length of the curing period; thus decreasing the permeability which can considerably improve their durability characteristics. This proved the requirement of foamed concrete specimen in low water absorption condition for the potential of foamed concrete to resist the chemical attack on its surface. Besides that, the water absorption rate will also affect the compressive strength of the specimen as well. The lower the water absorption rate will give a good compressive strength to mortar (Thokchom, Ghosh, & Ghosh,2009).

2.5.4 Porosity

In this study, the porosity test of foamed concrete was carried out by following ASTM C642-13 (Astm:C642-13, 2013). The porosity test was used to identify the durability of the foamed concrete specimen. The percentages of air void which consists in the specimen can be determined by porosity test. Besides identifying the durability of the specimen, porosity test also can identify the rate penetration of water into the specimen. For the specimen which have high porosity rate resulted in low durability. Hence, reduce porosity of the specimen will increase the durability of the specimen. This happened because the air void consisted in the specimen is higher. The reduction of porosity was due to finer and lighter particles of EPP as compared to OPC (Hussin et al., 2010). Therefore, the liquid will easily penetrate into the specimen.

Previous study on porosity (K.-H. Yang & Song, 2009) reported that, with density of 1400 kg/m^3 Alkali Activation (AA) cementless mortar pastes using GGBS with a higher fineness had a lower porosity, fewer unhydrated particles, and denser surface. It has been observed that the porosity of AA containing GGBS decreased as the increased percentage of GGBS in the mix. Also stated by (Nambiar & Ramamurthy, 2007) by using vacuum saturation method to determine porosity for both cement-sand and cement-sand-fly ash mixes, even with a reduction in density of foamed concrete, the porosity increase. This is because a relatively higher water-solids ratio produce a weaker and pervious matrix, leading to higher capillary porosity which is in turn responsible for the increase in water absorption of mixed with fly ash.

2.5.5 Compressive strength

Compressive strength of the mortar are affecting by several factors such as cement content, sand grading entrained air content and water content. Increased of cement contain will give higher strength, meanwhile increase of sand, water and air content will reduce the strength of mortar. According to (Kearsley & Wainwright, 2001) foamed concrete is manufactured of entraining relatively large volume of air into the cement paste by the use of a chemical foaming agent. High air contents result in lower densities, higher porosities and lower strength.

Previous study on foamed concrete utilising fly ash aggregates (Jones & McCarthy, 2005) stated that, with density of 1600 kg/m^3 , the compressive strength for 30% foamed concrete utilising fly ash fine aggregates (FA_{fine}) as cement replacement at the age of 28 days is 28 Mpa. This indicates that foamed concrete in structural applications is a realistic proposition although it is unlikely that a direct substitution for normal weight concrete should be attempted.

2.6 EFFECTIVENESS OF POZZOLAN MATERIAL IN FOAMED CONCRETE

2.6.1 Particles size

According to (Yetgin & Çavdar, 2006) natural pozzolan and clinkers have different grinding properties. Actually, it can be clearly observed and indicated in the sources that natural pozzolan can be more finely grained around 6,000 cm^2/g than clinker. Therefore, as the ratio of natural pozzolan present in the cement increased, natural pozzolan became the dominant factor determining the fineness of the cement, and therefore the main factor affecting the tests results was the natural pozzolan amount rather than the cement fineness.

2.6.2 Pozzolonic reaction

According to Pelisser, Barcelos, Santos, Peterson, & Bernardin (2012), the reactive silica present in the pozzolan materials was react with calcium hydroxide(CH) which produced during the hydration of cement leads to increase the principal product of reaction is calcium silicate hydrate (CSH). The reaction of mechanism of pozzolan materials is described as follow:

C_3S (tricalcium silicate) +H_2O $\longrightarrow$ C-S-H + CH (calcium hydroxide)

Reaction of EPP and calcium hydroxide

Pozzolan (S) + CH $\longrightarrow$ C-S-H

2.6.3 Chemical composition

Table 2 : Chemical Composition of Cement, Fly Ash and Pozzolan (Kearsley & Wainwright, 2001)

Parameters	RHPC from PPC Hercules (%)	Processed fly ash from Lethabo (%)	Pozz-fill from Lethabo (%)
CaO	61.7	4.7	5.0
SiO_2	21.2	53.9	54.8
Al_2O_3	4.6	33.5	31.7
Fe_2O_3	1.8	3.7	3.8
Na_2O	0.1	0.7	0.8
K_2O	0.7	0.7	0.8
MgO	4.3	1.3	1.1

SO_3%	2.0	0.1	0.3
CO_2	2.6		
Free CaO	1.2		
Loss on Ignition		0.8	0.8
BET Surface Area	431	350	280
Relative density	3.15	2.2	2.2

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter discussed the steps to perform the testing, preparation of materials, mixing and testing. All the preparation work and testing are carried out in the Concrete Laboratory of civil Engineering and Earth resources at University Malaysia Pahang (UMP).

Figure 3.0 showed the flowchart of the study. In this case, the laboratory works were carried out step by step to achieve the objectives. The flowchart was start with preparation of materials, casting of specimen and testing result.