PREDICTING INSULATION AND STRUCTURAL RESPONSE OF FOAMED CONCRETE PANEL

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PREDICTING INSULATION AND STRUCTURAL RESPONSE OF FOAMED CONCRETE PANEL

By

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MERAMALKAN PENEBATAN DAN TINDAK BALAS STRUKTUR DALAM PANEL KONKRIT BERBUSA

ABSTRAK

Konkrit ringan berbusa (LFC) dihasilkan daripada mortar atau campuran simen berserta gelembung udara yang dihasilkan daripada agen campuran tertentu. Penggunaan LFC sebagai bahan binaan menjadi prerogatif dalam industri pembinaan kerana ia memiliki banyak kelebihan seperti lebih ringan, kekuatan rendah dikawal dan sifat haba yang sangat baik. Kajian ini memberi tumpuan kepada sifat-sifat LFC dengan pelbagai bahan campuran dan ketumpatan serta potensi sistem panel dinding LFC dari segi prestasi ketahanan struktur dan api. Tiga jenis ketumpatan (700, 1000 dan 1400 kg/m^3) dengan campuran pelbagai bahan campuran (abu bahan api terhancur, abu kayu, abu bahan bakar minyak sawit, silica, fiber polipropilena, fiber keluli dan fiber sabut) telah disiasat. Kekuatan mampatan, kekuatan lenturan, kekuatan tegangan, penyerapan air, keliangan dan sifat haba adalah sifat-sifat yang diukur. Fiber sabut menunjukkan peningkatan yang sangat baik dari segi sifat mekanikal dan terma disebabkan oleh struktur molekul dalaman LFC. Fiber sabut dengan jumlah yang banyak telah terbukti agar mampu menghalang lebih banyak air daripada merentasi sampel LFC. LFC yang ketumpatan rendah menyumbang kepada sifat penebat terma yang baik akibat daripada keberkesanan dalam konduktiviti terma. Panel dinding LFC dengan fiber (FRLFC-prototaip) dengan saiz 0.3m x 0.3m dan ketebalannya 0.15m menunjukkan peningkatan sebanyak 27% di bawah mampatan paksi berbanding dengan sampel kawalan kerana campuran fiber mempunyai ketahanan yang kuat di bawah mampatan paksi. FRLFC (1.5m x 0.675m dan ketebalannya 0.15m) juga mempunyai keupayaan untuk mengurangkan kadar pemindahan haba kerana ia telah mempamerkan kapasiti haba yang tinggi.

PREDICTING INSULATION AND STRUCTURAL RESPONSE OF FOAMED CONCRETE PANEL

ABSTRACT

Lightweight foamed concrete (LFC) is produced by mortar or cement paste in which air-voids are entrapped in the mortar by means of suitable foaming agent. Demand and usage of LFC as building material become privileged in construction industry due to many advantages such as lighter weight, controlled low strength and excellent thermal properties. This research mainly focuses on the properties of LFC with various densities and additives with different percentages and also the potential application of LFC wall panel system in terms of structural and fire resistance performance. Three different densities of 700, 1000 and 1400kg/m^3 with various additives (Pulverized fuel ash, wood ash, palm oil fuel ash, silica fume, polypropylene fibre, steel fibre and coir fibre) were cast and investigated. Mechanical strength, durability and thermal properties were measured. Coir fibre showed an excellent improvement in the mechanical and thermal behaviour compared to other additives due to its internal molecular structure of the LFC. A high amount of coir fibre is proven to be able to inhibit more water from migrated through LFC specimen. Low density of LFC provided the best thermal insulation properties due to its effectiveness in thermal conductivity. Fibre reinforced LFC wall panel (FRLFC-prototype) with 0.3m x 0.3m and thickness of 0.15m showed an improvement of 27% under axial compression in comparison to the control sample because the fibre has strong resistance under axial compression. FRLFC (1.5m x 0.675m and thickness of 0.15m) also has the ability to diminish the rate of heat transfer because it has improved the interfacial adhesion between fibres and the matrix and exhibited high heat capacity.

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

In today's society, the advancement in construction industry plays an important role to discover the latest methods and technologies for the future. Traditional technology which utilizes conventional method in producing normal weight concrete has been established and being in use up to now. It is used for different applications in construction such as architectural structures, wall partitions, foundations, runaways and highways. However, new innovative materials that can cater for different construction purposes are significant these days. The selection of proper building materials has to be done in order to minimize energy usage in buildings. In addition, particular attention should be given to thermal insulation and fire resistance properties because low thermal conductive materials will enhance the thermal comfort of indoor environment.

In conjunction with that issue, the construction industry is seeking for a new building structure which will able to function as a thermal barrier, prevent heat and fire spread. Designing fire-proof building structures is constantly attracting more attention and of great importance. As a remedy for unforeseen circumstances due to uncontrolled fire, the construction industry is gradually switching their interests towards the use of lightweight foamed concrete (LFC) instead of using traditional concept building materials due to many advantageous characteristics such as being lighter in weight, as excellent thermal and acoustical insulation, is easy to fabricate, durable, minimal consumption of aggregates and cost effective. These noticeable qualities indicate its strong potential as a valuable material in building construction to increase indoor thermal comfort by reducing heat absorption.

LFC is described as a cementitious material with at least of 20 per cent by volume of mechanically entrained foam added to a cement paste or slurry (Van Deijk, 1992) in which air voids are entrapped by means of suitable foaming agent. LFC is also known as porous concrete. The most basic definition of foamed concrete is that "mortar with air bubbles". The air content is almost 75% by volume of the cement paste. LFC consists of Portland cement paste or cement filler matrix with homogeneous pore structure together with sand, water and foaming agent. LFC can be produced in a wide range of densities from 400 kg/m^3 to 1600 kg/m^3 by properly controlling the quantity of foam added to the cement paste and its compressive strength ranging from 0.5 – 10N/mm^2 respectively (Aldridge, 2005).

LFC is not a new material in the construction industry and surprisingly it has a long history. It was patented first in 1923 (Valore, 1954) and its usage was very limited until 1970. The Romans had used air entrainers to decrease density. Moreover, LFC was mostly used as an insulation material and its application as semi-structural lightweight material has increased after a few years. It was first applied in Netherlands for ground engineering and for void filling works and in the United Kingdom, a full-scaled assessment on the application of lightweight concrete as trench reinstatement was carried out in 1987. LFC can be laid down easily and it does not require compaction, vibrating or leveling. LFC can be used as a partition or light load bearing walls in low rise building although the mechanical properties of foamed concrete is low when compared to normal weight concrete.

The density and the mechanical properties are inversely proportional to the percentage of porosity of LFC. On the other hand, thermal conductivity of LFC is also influenced by the density of constituent materials in the mortar slurry. Therefore, the thermal conductivity can be reduced by replacing cement with finer particles such as fly ash and silica fume. The ingredients used to cast LFC into a desired shape are similar to that of conventional concrete. Foaming agent is used to generate foam with the aid of foam generator machine to substitute the place of aggregates. The contributions of LFC in speeding up the building rates and reducing the dead load of structural elements are essential for current building industry.

Due to its fluidity, it can be poured into various shapes and sizes to fulfill current worldly building design structures. Although LFC possess many attractive characteristics, its mechanical properties are lower compared to that of normal weight concrete. Previous studies that have been conducted by many researchers have sorted out this issue and it has been proven that LFC still can be used as a structural element in buildings. This experimental study is divided into two main stages. The first stage is to a conduct pilot study on the properties of LFC. At this stage, a detailed study and investigation were carried out to look into the properties of LFC with different densities and additives. The results from the investigations will be used for further applications. In the second phase, experiments are performed to observe fire resistance and structural performance of LFC wall panel in a big scale by means of suitable procedure and equipment.

1.2 PROBLEM STATEMENT

In construction industry, providing a system to control fires is a great implication of engineering practice because uncontrolled fires can cause serious injuries, fatalities and economic loss. Typical practice in fire protection is making compartments in building using fire resistant barriers in order to prevent fire from spreading to other areas. As mentioned earlier, discovering building structures against fire is constantly attracting more attention and is of great significance. Therefore, it is necessary for the construction industry to shift its importance towards the use of LFC due to excellent fire resistance properties and acoustical insulation compared to that of conventional concrete. Not only that, the demand is increasing because of its some other notable characteristics such as low self-weight, durability, and cost effective.

However, the major problem with LFC is its lower strength compared to normal weight concrete. Therefore, it has constructed a barrier for further applications in building construction though it contributes to excellent thermal insulation. The addition of some materials as additives into mortar slurry has a potential to enhance the mechanical properties of LFC. Previously, only a few researches have been conducted to look into the effects of additives on the strength of LFC. Sustainability is the serious issue all over the world. Releasing of carbon dioxide has been a severe problem in the world due to greenhouse effect. The use of cement replacement and other abundant materials with optimum content of cement and enhancement of concrete durability are the main issue towards sustainability in concrete industry. The study of fire resistance performance of any structural element is of great significance, more so for a new and innovative material like LFC. However, quantitative information on fire resistance performance of LFC is extremely sparse. According to Jones and McCarthy (2005), a majority of researchers previously have just focused on the mechanical properties and only a few on thermal properties of LFC.

As mentioned earlier, the construction industry is searching for a building material which has good fire insulation and is potential to be a load bearing structure in buildings. Therefore, studies on the fire resistance and structural performance of LFC are required to provide more knowledge on the subject of LFC. Unfortunately, no studies have been conducted on the effect of additives on fire resistance and structural performance of LFC wall panel. As a conclusion, this research focuses on the properties of LFC with different types and percentages of additives to enhance further its mechanical and thermal properties. This stage is to obtain reliable thermal and mechanical properties for quantification of its fire resistance performance and some indication whether it has enough load bearing performance. Then, as main activities of this research the structural behaviour and fire resistance performance of LFC wall panel under axial compression and fire test were examined respectively to conclude the potential of LFC for the application as a load bearing structure in building construction. The use of additive in LFC wall panel is to reinforce the structure and to provide better thermal properties. The findings from this research will address the knowledge gap in the subject of LFC and will provide an improved understanding and raised awareness of the fire resistance performance of LFC based system.

1.3 OBJECTIVES OF RESEARCH

The main objectives of this study are:

i. To investigate the mechanical properties and durability of LFC by incorporating various types and percentages of additives.
ii. To determine the thermal properties of LFC with the addition of different types and percentages of additives
iii. To observe and determine the fire resistance performance and structural behaviour of LFC wall panel.

1.4 SIGNIFICANCE OF RESEARCH

LFC is relatively a new innovative building material in the construction industry. Lack of knowledge on the performance of material is the main reason which restricts the usage of LFC in applications. This research will provide a detailed understanding with comprehensive justification on the properties of LFC to promote its demand in the construction industry. In order to quantify the performance of LFC based system, mechanical and thermal properties must be made known earlier. Furthermore, knowledge of thermal properties of LFC with additives at ambient temperature is essential to quantify its fire resistance performance. Its significant values such as thermal conductivity, specific heat, porosity and density must be taken into consideration in determining thermal properties of LFC.

The temperature in the structure must be determined in order to predict the building structure's fire resistance. Besides that, compressive, flexural and tensile strength must be established to demonstrate whether it has adequate load bearing capacity. The utilization of some additives in this study is predicted to enhance the durability of the concrete and thus it will indirectly offer a better understanding to future researchers who been working in the field of foamed concrete technology. The proposed design of LFC wall panel is expected to reduce the total weight of the whole panel. It can be constructed quickly and easily owing to its low density compared to that of normal weight concrete. Finally, this research will provide detailed explanations on the structural and thermal properties of LFC and will promote it to be a building material for low rise construction.

1.5 SCOPE OF STUDY

This present research will cover the thermal, mechanical and durability properties of LFC. For this study, LFC specimens with different densities (700kg/m^3, 1000kg/m^3 and 1400kg/m^3) were prepared to observe the effects of different densities on their mechanical and thermal properties. At the same time, specimens with different additives were also cast at a density of 1000kg/m^3 and observed to examine the variations in the mechanical, durability and thermal insulation properties. Hardened specimens such as cube (100x100x100mm), prisms (100x100x500mm) and cylinder (100mm diameter and 200mm length) will be prepared and tested to look into the thermal, mechanical and durable properties of LFC.

All specimens cast for this study will be sealed curing. This sealed curing regime is advisable for low density LFC and it is better than water curing condition because water curing method is unable to produce complete curing for low density samples of less than 1000kg/m^3 (water density). The cement-sand ratio, water-cement ratio, type of cement and content, pore size and distribution, type of foaming agents and curing regime are the main factors that influence the strength of LFC. Therefore, in this research the water cement ratio is fixed at 0.45. Meanwhile, the cement sand ratio is 1:1.5 for all mixes. LFC wall panel will be designed and casted at the final stage of this research to observe its structural response and fire resistance performance.

1.6 THESIS ORGANISATION

The chapters for this thesis will be organized according to their sequence and each chapter will describe its function in providing a detailed understanding of this overall study. This research is organized in the following six chapters:

Chapter 1 presents a general introduction to the project and the thesis.

Chapter 2 provides relevant literature review on the properties of LFC, including its application. Also in this chapter, the behaviour and reaction of each material including the additives used for this study would be discussed briefly. Limitations in the previous studies would be identified and further knowledge would be provided as a platform for a better understanding of this project.

Chapter 3 explains comprehensively the methodology used in this study including the experiments and investigations that were carried out. This chapter discusses the overall experimental study of the properties of LFC. This section will provide clear details on the design of LFC wall panel and the experimental setup for fire resistance and structural performance test.

Chapter 4 discusses the results of the mechanical properties of LFC such as compressive, flexural and splitting tensile strength and the durability test results such as water absorption and porosity with three different densities and various percentages of different additives. Detailed investigations were conducted in relation to several aspects such as the characteristics and the reaction of additives and hydration process. In addition, this chapter describes the thermal properties of LFC with three different densities and additives. Thermal tests were conducted by means of Hot Disk Thermal Constant Analyzer and essential values such as thermal conductivity, thermal diffusivity and specific heat capacity were recorded for further analysis.

Chapter 5 presents experimental results on fire resistance and structural performance of LFC wall panel. The best additive selected from the analysis of mechanical and thermal properties results presented in Chapter 4 would be discussed. This chapter will discuss both controlled and fibre reinforced LFC wall panels that experimented to evaluate their potential under fire and structural test.

Chapter 6 summarizes the results obtained from this study and proposes recommendations for further research studies to gain an extensive knowledge of LFC.

CHAPTER 2

LITERATURE REVIEW

The main aim of this research is to experimentally investigate the properties of lightweight foamed concrete (LFC) with several additives and its performance in terms of structural and fire resistance. This study is expected to fulfill the knowledge gaps in the field of fire resistance performance of LFC based system. This chapter will review the literature on the properties of LFC, including its mechanical (compressive, flexural and tensile), durability (porosity, water absorption and microstructure) and thermal performance. This input will provide a better understanding on the utilization of LFC in lightweight walling system. The results and findings of previous researches would be reviewed and analyzed thoroughly in order to obtain fundamental properties so as to produce a better outcome at the end of this experimental investigation for the application of LFC as building material in the construction industry.

2.1 INTRODUCTION TO LIGHTWEIGHT FOAMED CONCRETE (LFC)

LFC is a cementitious material which consists of components such as sand, ordinary Portland cement, water and stable foam. Aggregate is one of the main constituent materials for conventional concrete which will be replaced by foam in the making of LFC. A metered volume of preformed foam was incorporated to entrain air voids into a cement paste or mortar mix. The preformed foam is developed in the foam generator machine from foaming agent mixed with water and air. This foam plays a vital role in changing the density of LFC by inhibiting millions of evenly distributed, consistently sized bubbles. Foam can be concluded as an expanding agent which can promote the volume of slurry mix while increasing some extra properties. According to Aldridge (2005), the term of LFC is itself misleading because the majority of western LFC contain no large aggregates. It consists of only fine sand, cement, water and foaming agent. Therefore, the final products should be described with the right term which is foamed mortar. According to Van Deijk (1992), LFC is specially manufactured containing a minimum of 20 per cent by volume of air with pre-formed foam or foaming agent incorporated into a cementitious base mix. During the mixing, placing and hardening process of the concrete, the stable air bubbles in the foam are able to resist the imposed physical and chemical forces.

LFC was firstly introduced by the Romans in the second century and has a very interesting history. It was already patented in 1923 (Valore, 1954). Therefore, LFC is no longer a new material in the construction field. The usage of LFC was limited due to lack of specialized materials and equipment until the late 1970s. In the late 1980s and 1990s, development of research on LFC was carried out in Netherlands. The Reinstatements of Openings in Highways (1996) helped in increasing the production and broadening of the scope of application of LFC in UK in the last 19 years. Since then, LFC as a building material has become widespread with its expanding productions and various applications. In 1914, Swedes found that the addition of aluminium powder could generate hydrogen gas in the cement slurry. It was lately reported that LFC has been discovered in Europe over 60 years ago and it was more than 20 years since it has been in the international market.

LFC is also known as porous concrete and it is noticeable because of its favorable characteristics. It has highly flow ability, low self-weight, controlled low strength and excellent thermal properties. Though LFC has very low strength compared to the conventional concrete, it shows a positive response in terms of thermal and acoustical properties. One of its interesting characteristics is that the density of LFC can be changeable depending on its applications. Previous studies revealed that the dry density of LFC is varied from 400kg/m^3 to 1600kg/m^3 and the range of compressive strengths is from 0.5 – 10N/mm2 (Aldridge, 2005). It is 87% to 23% lighter than the conventional concrete. According to Liew (2005), there are several ways to reduce the density of concrete by using lightweight aggregates, foam, high air concrete and no-fine aggregate. The LFC density depends on the amount of foam added to the mixture by foam generator. It lessens the dead load by becoming lighter when compared to conventional concrete.

The higher air content of the LFC will result in the lower density, higher porosity and the decrease of strength. The size of the bubbles are typically 0.3-0.4mm diameter enclosed by cement. The stability of foam is actually created by these bubbles in foamed mortar. Meanwhile, the bubbles produced from the foam machine will replace the coarse aggregates and will cause the reduction of the density and compressive strength as well. The air voids in low density LFC are typically bigger than in the high density because of the dosage of foam added. The high amount of foam will generate more continuous and connected pores within the concrete but on the other hand, less connected pores can be observed in high density as shown in Figure 2.1.

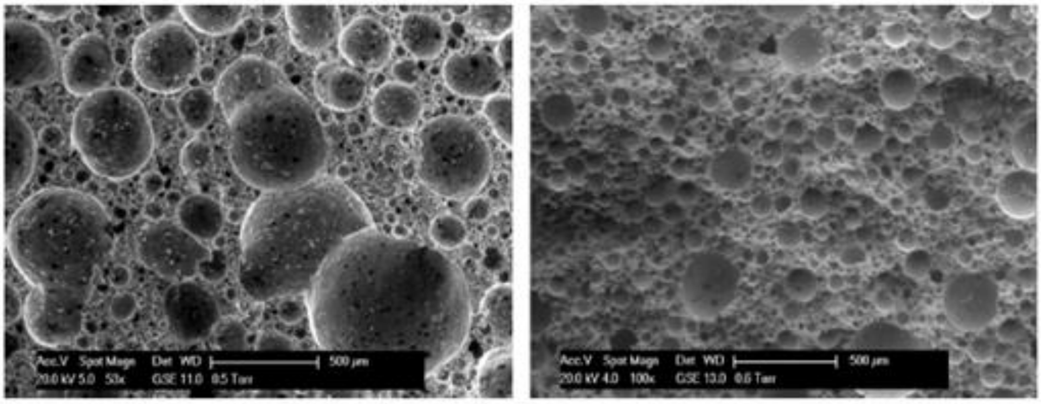

Figure 2.1 Air voids in 500kg/m^3 (left) and 1000kg/m^3 (right) (Wei et al., 2013)

2.1.1 Advantages and disadvantages of LFC

LFC has more advantages in terms of its properties compared to normal strength concrete. It has faster building rate in construction industry and also the reduction of dead load. Since LFC is lightweight, it has low handling cost and lower haulage. The advantage of lower LFC density is excellent thermal conductivity which can give better insulation properties in terms of fire resistance and sound absorption due to the cellular microstructure (Ramamurthy et al., 2009). Aldridge and Ansell (2001) found that thermal conductivity of LFC sample with a density of 1000kg/m^3 is reported to be one-sixth of the value of common cement-sand mortar.

The values of thermal conductivity are 5-30% of those recorded on normal weight concrete and the range is between 0.1 W/mK and 0.7 W/mK for dry densities of 600-1600kg/m^3 (Jones and McCarthy, 2005). LFC is classified to be less efficient than denser concrete in reducing the transmission of air-borne sound (Taylor, 1969). Normal weight concrete tends to deflect sound waves but LFC absorbs it. Therefore, it can be said that LFC has higher sound absorption capacity. Meanwhile, Valore

(1954) stated that this cellular concrete does not contain significant acoustic insulation characteristic. On the other hand, LFC has its disadvantages as well as shown in Table 2.1.

Table 2.1 Advantages and disadvantages of LFC (Source: Neville, 1985)

<table>
<tr><th>Advantages</th><th>Disadvantages</th></tr>
<tr><td>Rapid and relatively simple construction</td><td>Very sensitive with water content in the mixture</td></tr>
<tr><td>Economical in terms of transportation as well as in reduction of manpower</td><td rowspan="2">Difficult to place and finish because of the porosity and angularity of the aggregate. In some mixes, the cement mortar may separate the aggregate and floats towards the surface</td></tr>
<tr><td>Significant reduction of overall weight results in saving structural frames, footing or piles</td></tr>
<tr><td>Most of lightweight concrete have better nailing and sawing properties than stronger conventional concrete</td><td>Mixing time is longer than that of conventional concrete to assure proper mixing</td></tr>
</table>

2.1.2 Applications of LFC

Basically, LFC can be used as structural components, non-structural partitions and thermal insulating elements (Rudnai, 1963). In order to fulfill these requirements for each application, various density of LFC must be developed. The range of density (300kg/m^3 – 1840kg/m^3) plays an important role in the applications such as trench reinstatement, bridge abutment, large void filling works, bulk filling, backfills for retaining walls, insulation for foundations and roof tiles, pipeline infill and grouting for tunnel works, sound insulation and sandwich fill for precast units. According to Gao et al., (1997), drops in density of LFC with the same level of strength permits the preservation of dead loads for structural design and foundation. The application elements can be structural, partially-structural and non-structural and the LFC high density product will be used as structural building elements. Meanwhile partially structural elements will be occupied by medium density and low density material will be for non-structural elements. Table 2.2 shows various applications of LFC with different density.

Table 2.2 Applications of LFC with different densities, (www.litebuilt.com)

Density	Applications
Density 300-600kg/m^3 (Made of cement & sand)	• Used in roof and as insulation against heat and sound • Interspace filling between brickwork leaves • Insulation in hollow blocks and any other filling situation
Density of 600-900kg/m^3 (Made of sand, cement and foam)	• Manufacture of precast blocks and panels • Slabs for false ceilings • Thermal insulation and soundproofing screeds • Bulk fill application
Density of 900-1200kg/m^3 (Made of sand, cement and foam)	• Used in concrete blocks and panels for outer leaves of buildings • Architectural ornamentation as well as partition walls
Density of 1200-1600kg/m^3 Made of sand, cement and foam)	• Used in precast panels of any dimension for commercial and industrial use • In-situ casting of walls, garden ornaments and other use

LFC can be used as lightweight blocks or bricks for high rise building. Also, panels and partitions can be produced by precast and cast in-situ from LFC. It can be used for low cost terrace house, bungalows and low rise building construction as partitions. According to Nooraini et al., (2009), the water absorption by LFC blocks is lesser than that of the bricks, hence, it has a longer lifespan. Since LFC has good thermal insulation properties, its contributions for the construction industry, especially in insulation works, are mostly acceptable. Being low in weight and having better thermal properties make LFC potential to be used in housing applications. According to Jones and McCarthy (2005), LFC has already been used as roofing insulation material in South Africa, however its low density influences the creation of roof slopes.

Besides that, LFC has been used in the manufacture of support structure in mining areas in South Africa and a research has been conducted on thermal resistant performance in Ukraine. In Malaysia, the application of LFC as wall panel attracts the attention of developers and is becoming popular within these 10 years. The major application of LFC is SMART tunneling project in Kuala Lumpur. LFC was used to shield the diaphragm wall when the tunneling machine was removed to the junction box. In the Middle and Far East area, 3000 residential buildings were constructed using LFC with a density of between 1100 to 1500 kg/m^3 in 1948 and 1958. After 25 years, the buildings were assessed and it was found that these buildings required the least maintenance compared to buildings constructed with contemporary timber or bricks and concrete (Nooraini et al., 2009).

2.2 CONSTITUENT MATERIALS OF LFC

LFC is produced from cement, fine sand, water and chemical agent (stable foam). The next section will give brief discussion on the properties and requirements of each material used for better understanding.

2.2.1 Ordinary Portland cement

Ordinary Portland Cement (OPC) is the main binder for the production of LFC. Rapid hardening Portland cement (Kearsley and Wainwright, 2001) which contains high alumina and calcium Sulfo-aluminate (Turner, 2001) are used to reduce the setting time and to develop the initial strength of the LFC. In Ordinary Portland cement, the main chemical components are limestone, alumina and silica which are vital to form calcium silicate hydrate (CSH) gel during hydration process. The fine inorganic element will form a paste called cement paste after water has been added added to the mixture.

According to BS12:1996, ordinary Portland cement usually functions as the main binder in LFC. Previously, most researchers had attempted to reduce the usage of cement in LFC by replacing other materials as alternative due to their concern on the sustainability aspect and wise. The study conducted by Kearsley and Wainwright, (2001) revealed that cement can be replaced by fly ash, which is an industrial waste, to enhance the properties of LFC by reducing the temperature during hydration process.

2.2.2 Sand

Sach and Seifert (1999) suggested only fine sand (BS 882:1992) or mortar (BS: 1200:1976) and particle sizes up to 4mm should be used for LFC. According to Noordin (2000), the sand used for LFC should be fine with the sizes of between 0-2mm because coarse aggregates may affect the stability of foam during the mixing process. Higher strength of LFC attributes to the relatively uniform pore distribution by using fine sand while mixtures with coarse sand will produce larger and irregular pores. The types of sands that are usually used to produce LFC normally consist of natural sand, manufactured sand or a combination of both.

Fine aggregates that are subjected wetting should not have any impurities that will cause destructive reaction in the cement. It will result in excessive expansion and will lead to the cracking of concrete. Fly ash can be partial or total replacement for sand in order to produce LFC below 1400kg/m^3 according to (BS 3892: Part 1:1997). Fly ash is very fine particles than sand. If fly ash were to be replaced with sand, the compressive strength of the LFC will therefore be increased. In a study, Nambiar & Ramamurthy (2006) showed finer the filler, the higher the ratio of strength will be achieved. The absence of aggregates will lead to shrinkage problem in LFC. However, other materials can be used as a replacement of aggregates in order to reduce the shrinkage problem.

2.3 Water

Water plays an important role in producing workable concrete which will form into a paste after being mixed with other materials. The PH value of water should be between 6 to 8 which is not tested and the criteria of portability of water is not absolute. The amount of water should be kept under control so as to reduce the shrinkage in LFC after it has dried. The amount of cement in the mixture and use of chemical admixtures will influence the amount of water added during the mixing. Karl and Worner (1993) found that water requirement for a mixture should depend on the consistency and stability of that mixture.

An appropriate amount of water is necessary to prevent the foam from being damaged in the mix (Mydin, 2010). The compressive strength of the concrete may be reduced by water containing algae in the mixing procedure because this will result in air entrainment in the paste. Sea water is rich in chlorides which can be the major cause of the corrosion of the reinforcement concrete. Neville and Brooks (2001) stated that the water used in the mix composition must be clear and apparently clean. Narayanan and Ramamurthy (2000) mentioned that low water content will cause the mix to become too stiff thereby causing air bubbles to break up. The mix will be too thin to hold the bubbles if a high amount of water is being added, thereby leading to the segregation of bubbles.

2.2.4 Foaming agent

Foaming agent plays a vital role in the manufacturing of LFC. It is also known as "air entraining agent" because the air bubbles inside LFC are produced by this foaming agent. LFC can be produced by preformed foaming method and mixed foaming method. Preformed-foaming method is the means of producing base mix and stable foam and then blending them together. On the other hand, mixed foaming method is where the foaming agent is mixed together with the base matrix and during the process, foam is produced. In the early 1950's, preformed foam was developed by following the growth of foam generating materials that are highly refined from stabilizers. The method has the potential to control the density effectively. In order to develop the properties of conventional concrete, preformed foam is commonly added to the cement paste to produce LFC. It can be split into two groups which are protein based material and synthetic foaming agents.

It was found that pre-formed foam method is more beneficial than mixed foaming method. Lower foaming agent is required in pre-formed technique and there is a close relationship between air content in the mix and the amount of foaming agent (Ramamurthy et al., 2009). Foaming agent can be classified as air entraining surfactants which later will be incorporated into the cement paste. In order to resist the pressure of a mortar until the cement takes its initial set, and strong bonding in concrete is built up around the air pores, the foam added must be firm and stable (Koudriashoff, 1949). The preformed method can be produced either on dry or wet foam. Wet foam is produced by sprinkling a solution of surfactants over a fine mesh. It has 2-5mm size bubbles and is relatively less stable. However, dry foam is extremely stable and its bubbles size smaller than 1mm which makes it easily applicable with the base material for generating a pump able LFC (Aldridge, 2005).

The properties of foam are mainly related to the quality of the foam. Synthetic foaming agents are purely chemical solutions which are applicable to LFC density of 1000kg/m^3 and they are very stable and very durable. The foam has finer bubbles compared to protein based materials but it is generally contributes to low strength especially at densities below 1000kg/m^3 (Brady and Jones, 2001). According to Alex Liew (2003), the ratio of protein based foam added to water is 1:30 to create discrete bubble cavities in the mortar after being incorporated into it. The weight of protein foam is between 60-80gram/liter. On the other hand, the weight of synthetic foaming agent is only 40gram/liter. In order to produce stable foam practically, a portable foaming generator will be purchased from the Malaysian Manufacturer (www.portafoam.com).

2.2.5 Additives

This section is fully concerned with the characteristics of additives which can give positive changes to LFC properties. Many researchers have studied several ways of improving the properties of LFC by adding different materials as additives. There are some additives with distinct behaviors which were found and investigated by previous researches, to improve the properties of LFC. The additives can be added by cement replacement or as the total volume of fraction because each additive used will affect the characteristics of LFC in different ways. In fact, fly ash can be used as a total or partial replacement for sand to produce LFC with noticeable strength below dry density of 1400kg/m^3 in accordance to BS 3892: Part 1: 1997. Fly ash is the major by-product of industrial waste which can be obtained from exhaust gases of coal-fire power stations and utilized as filler. It is also of great significance to economy and the environment (Papadakis, 2000). According to Mehta and Monteiro (2006), the utilization of fly ash in LFC has numerous advantages such as minimizing greenhouse emission, providing better long term strength and durability, lowering water content, reducing energy consumption and pressure on natural resources.

According to Neville, (2005), high specific area of fly ash particles are able to react with calcium hydroxide during the hydration process. The particles of fly ash normally have a diameter of between 1µm and 100µm and the surface area between 250 and 600m^2/kg. In addition, during cement hydration, the silicon oxide and aluminium oxide of fly ash will react to calcium hydroxide to form additional calcium silicate hydrate and calcium aluminate hydrate thereby forming a denser matrix which will result in higher strength and better durability (Bendapudi, 2011). High percentages of ash in LFC will reduce early compressive strength due to pozzolanic reaction during the early stage of hydration process. The hydration process transforms the complex particles from different sizes and shapes to another form at different phases (Hanizam et al., 2012). The reaction of fly ash in hydration will be completed after 150 days according to Narayanan and Ramamurthy (1999). The sphere particle is then transformed into some prismatic members with semi-crystalline gel.

According to Tay and Show (1995) and Tangchirapat et al., (2009), palm oil fuel ash (POFA) is considered as a cement replacement in LFC mixing because of the pozzolanic properties. According to MPOB (2010), approximately 61.1 million tonnes of solid waste by-products in the form of fibers are produced which is about

70% of fresh fruit bunches being processed. POFA contains a high amount of silicon dioxide in amorphous form which can produce calcium silicate hydrates gel (CSH) when it reacts together with calcium hydroxide generated from the hydration process (Karim et al., 2011). However, Eldagal (2008) stated that the products of pozzolanic reaction cannot be obtained from primary cement reaction. The unprocessed POFA particles have angular shapes and porous structures (Hussin et al., 2010) and the water absorbed by porous POFA particles do not contribute to the flow ability of the LFC mix but reduce fluidity.

Silica fume is known as micro silica which is a by-product of the production of silicon and ferrosilicon alloys which releases silicon oxide during the process. This can be oxidized to form them into very fine spherical particles of SiO2 (Sipple, 2009). This process will accelerate the reaction with calcium hydroxide produced during the hydration of cement due to the presence of small highly reactive silica particles. Small silica particles are capable of filling up the empty spaces between cement particles due to free water, thus they will improve strength. Silica fume contains very fine vitreous particles with the surface area ranging from 13,000 to 30,000m^2/kg (Sipple, 2009). Each particle of silica fume is approximately 100 times smaller than cement particles. Luther (1990), stated that silica fume is a highly effective pozzolanic material due to the large content of fine silica. Neville (2005) stated that the reduction in size and amount of capillaries is able to reduce the permeability of the concrete.

Wood ash is categorized as a replacement for filler but it does not have high pozzolanic properties as fly ash, silica fume or POFA (Abdullahi, 2006). The total