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## CHAPTER 1

### INTRODUCTION

#### 1.1 Introduction

One most challenge to the construction industry in this century is building sustainably. As known, concrete is one of the most popular construction materials used since hundred years ago. Because of its flexibility is usage many structures around us constructing by concrete. It becomes more important and is preferred compared to timber or steel however , it largest consumer of natural resources .in addition , about 7% of the world's carbon dioxide emissions are attributable to Portland cement and it's more energy intensive . The cement manufactures consume about 7600000 kj per ton of cement (Naik et al 1996). This technological advancement forms a challenge to mankind to look into various ways and means to improve concrete.

However, continuous research in area of concrete material and innovations has been made to cope with challenges of many construction aspects. One of the most concrete that becoming famous usage nowadays among the contractors is lightweight concrete due to its physical properties/ characteristics make it an obvious choice as a medium of construction. It is particularly suitable for high- technology special structures where, apart from the response to reduce the cost and environmental impact are considered.

Many productions of lightweight concrete (LWC ) had been designed to successfully used in wide range of construction from conventional dwelling to complex highly specialised structure. For heat insulation, thermal acoustic application, void infilling, roof-deck insulation application, bridge approach for

undulating prevention, bridge deck, soft ground base for roads, for housing raft foundation and many more on infrastructure applications pre cast and cast in-situ.

Use of LWC instead of normal weight concrete (NWC), for example, as a floor slab in a multi-story building, depends on the relative costs and the potential savings that can occur by the use of a lighter material. LWC is about 28% lighter than normal concrete and, in a design where the dead load is equal to the live load, a saving of 14% in energy intensive steel reinforcement can result (Topcu IB, 1997).

Foamed concrete is one type of the light weight concrete and classified cellular concrete. Foam concrete is a free flowing, self levelling; material that does not require compaction. It is created by uniform distribution of air bubbles throughout the mass of concrete. It is a mortar or concrete based material that is normally made to low density by air entraining or foaming.

The properties of foamed concrete can vary widely, and can be used in a wide variety of application. Material selection is one important factor effects in properties of foamed concrete. The physical characteristics of foam concrete are determined by various mix designs. These may include the use of Portland cement either on it's own or in combination with a percentage of Pulverized Fly Ash, limestone dust or sand. Therefore, this study focuses to know the character of foamed concrete when the basic mix includes clay sand as a fine aggregate.

## **1.2 Problem statement**

Normal concrete (with natural aggregate) has density range between 2200 to 2600 kg/m<sup>3</sup>. The self normal weight concrete element is high and result to high load on structure. Foamed concrete represent decrease load solution and others concrete character improvement.

The construction sector is growing larger as there are lots of multimillion projects in Malaysia. As a result, there is higher demand for construction materials which may generate a lot of saving for the project.

Many researchers have conducted to study different physical and mechanical properties of foamed concrete continent different mixes. Most of the published investigations on foam concrete have been confined to neat cement paste, cement

paste with partial replacement with admixtures and to cement–sand and fly ash mixes such as those were done by Kearsley, Wainwright, Kunhanadan and Ramamurthy. Also, almost lightweight concrete companies provide information about foamed concrete in basic mix using sand as international market Lightweight Concrete Methodology (LCM).

Because clay sand is an available nature materiel with lower cost usage in normal concrete has been show a good result(Nurul Farhaana,2010), causes of this consideration and inclusion under research. This study will investigate the compressive strength as important characteristic of concrete ,work ability, water absorption and drying shrinkage to know the acceptable usage clay sand in foamed concrete instead of normal sand also, as a step to improve the knowledge and experience of this material.

### **1.3 Objectives of study**

The objectives of this study are:

- I. To determine physical properties (work ability water absorption and drying shrinkage) of clay sand foamed concrete.
- II. To determine mechanical strengths (compressive splitting tensile and flexural strengths) of clay sand foamed concrete.
- III. To establish strength model for clay sand foamed concrete.
- IV. To establish carbonation model for clay sand foamed concrete.
- V. To identify clay sand foamed concrete as one of engineering material to be used in construction.

This study focus to analysis the clay sand foamed concrete properties of concrete in the fresh and hardened states. In the fresh state, workability and workability retention were investigated. Whereas, in the case of hardened concrete, compressive strength, water absorption as well as carbonation were studied. In addition, the strength model and carbonation model were determined.

## 1.4 Scope of study

This project focuses on preparing 6 mixes of foamed concrete with target densities (1000-1500 kg/m<sup>3</sup>) containing portland cement, clay sand, and foam. Compressive strength will be determined on 100mm cube samples at 7, 14, 28, and 90 days. Also, water absorption will be studied on the same specimen type and age. Carbonation depth will be identified on the new crushed surface at the same age. Flexural strength will be tested on a concrete prism (100x100x500mm) at 28 days, and splitting tensile strength will be determined on a concrete cylinder (Φ150mm x 300mm length) at the same day. Drying shrinkage will be investigated using (Φ150mm x 300mm length) concrete cylinders until 90 days. Spreadability tests will be used to assess the workability of the concrete mixes. All samples for hardened concrete tests will be cured in air at room temperature.

The scope of this study will focus on:

- I. Preparation of clay sand foamed concrete with densities 1000, 1100, 1200, 1300, 1400 and 1500 kg/m<sup>3</sup>.
- II. Experimental study of properties of clay sand foamed concrete.
- II. Analytical study to determine strength model and carbonation model of clay sand foamed concrete.

## 2.5 Summary

This chapter describes the general idea about the study, the problem, objectives, and scope. However, the next chapter presents background information on the basic concepts of foamed concrete history, definition, manufacturing, properties, and application. Then, a literature review on previous work related to the objective of the study is presented to enhance the knowledge and help to decide the right process to achieve the project target.

## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 Introduction**

Light weight foamed concrete has become more popular in recent years owing to the tremendous advantages it offers over the conventional concrete. Modern technology and a better understanding of the concrete have also helped much in the promotion and use of light weight foamed concrete.

This chapter describes the nature of foamed concrete, its composition and properties and how it use in civil engineering works. Because the properties of foamed concrete can vary widely, and it can be used in a wide variety of applications, it is important to define performance requirements for each case.

#### **2.2 Overview of foamed concrete**

##### **2.2.1 Definition of foamed concrete**

Foamed concrete has been defined in several ways; indeed it has number of synonyms such as cellular concrete and there is confusion between foamed concrete and similar materials such as air entrained concrete. A definition, cited by Jones (2005), is that foamed concrete is a cementation material having a

minimum of 20 percent (by volume) of mechanically entrained foam in the plastic mortar. This differentiates foamed concrete from:

- (a) Gas or aerated concrete, where the bubbles are chemically formed through the reaction of aluminium powder with calcium hydroxide and other alkalis released by cement hydration.
- (b) Air entrained concrete, which has a much lower volume of entrained air.

Other definition, according to Aldridge (2005), that the term foamed concrete is itself misleading with vast majority of concretes containing no large aggregates, only fine sand and with the extremely light weight foamed concrete materials containing only cement, water and foamed, so the product should be more accurately described as having an air content of more than 25% which distinguishes it from highly air entrained. In its basic form foamed concrete is blend of sand, cement, water and pre-formed foam, which in itself is a mixture of foaming agent (either synthetic or protein base), water and air.

### **2.2.2 History and background of foamed concrete**

Foamed concrete is not a particularly new material, it is first recorded use date back to the early 1920s. The application of foamed concrete for construction works was not recognized until the late 1970s, when it began to be used in Sweden in 1929s.

The first large foamed concrete project in the UK was completed in 1980 at the Falkirk Railway Tunnel in Scotland. Around 4500m<sup>3</sup> of 1100 kg/m<sup>3</sup> foamed concrete was placed in the annulus space surrounding the tunnel.

The largest project in the UK required around 70,000m<sup>3</sup> of 500kg/m<sup>3</sup> foamed concrete encapsulating the utilities supply pipe and cable in the road foundation at Canary Wharf in London.

Significant improvements in production methods and quality of foaming agent over the last 16 years have lead to increased production of wide range of

application such as blocks, void fill and road. From there on, the use of Foamed concrete has been widely spread across world-wide (Andrew&Willian, 1978).

### **2.2.3 Comparison between foam concrete and conventional concrete**

Lightweight foamed concrete made with combination of cement, water, fine aggregate and foam agent have very fine pore structure, unlike that made with conventional concrete.

Foam or bubbling agent is used to absorb humidity for as long as the product is exposed to the atmosphere, allowing the hydration process of the cement to continue for its ever-continuing strength development.

As in a normal concrete the greater the air content the weaker the material, so with foamed concrete densities ranging from 300 to 1700 kg/m<sup>3</sup> it is not surprising that the lower densities produce the lower strengths and at present even the densities at the upper limits do not produce strengths much above 15 N/mm<sup>2</sup>(Aldridge,2005).

### **2.2.4 Manufacture of foamed concrete**

Foamed concrete is produced by entrapping numerous small bubbles of air in cement paste or mortar. Mechanical foaming can take place in two principal ways:

- By pre-foaming a suitable foaming agent with water and then combining the foam with paste or mortar.
- By adding a quantity of foaming agent to the slurry and whisking the mixture into a stable mass with the required density.

To get a high performance and quality foamed concrete, the selection of the materials are very important. The various materials, equipments and procedure are discussed separately below.

## **2.2.5 Basic material**

### **1. Portland cement**

There are many types of Portland cement .high alumina cement; super sulphate and special cement as masonry. Under ASTM standard the type (I, II, III) is preferred to use because its fineness and chemical composition.

However, Ordinary Portland cement (to BS 12:1996 or BS EN 197: Part 1: 2000) is usually used as tile main binder for foamed concrete. However rapid-hardening Portland cement to BS 915:1983 has also been used, and there does not seem to be any evidence why sulfate resisting cement could not be used.

Portland cement is essentially calcium silicate cement, which is produced by firing to partial fusion, at high temperature approximately 1500 C°. It has different rheological and strength characteristics, especially use in combination with chemical admixtures and supplementary cementing materials. Therefore, it is necessary to look at its fitness and chemistry content when choosing.

### **2. Fine aggregate**

Generally the fine aggregate shall consist of natural sand, manufactured sand or combination of them. The fine aggregate for concrete that subjected wetting, extended exposure to humid atmosphere, or contact with moist ground shall not contain any material that deleteriously reactive in cement to cause excessive expansion of mortar concrete.

Recommend that only fine sands suitable for concrete (to BS 882:1992) or mortar (to BS 1200: 1976) having particle sizes up to about 4 mm and with an even distribution of sizes should be used for foamed concrete. This is mainly because coarser aggregate might settle in a lightweight mix and lead to collapse of the foam during mixing.

### 3. Water

The water used for foamed concrete should be potable. This is crucial when using a protein based foaming agent because organic contamination can have an adverse effect on the quality of the foam, and hence the concrete produced.

The water/cement (w/c) ratio of the base mix required to achieve adequate workability is dependent upon the type of binder(s), the required strength of the concrete, and whether or not a water reducing or a plasticizing agent has been used. In most cases the value will be between 0.4 and 0.8. The higher values are required with finer grained binders, such as PFA, and the lower values where either a high strength is required or a super plasticizer has been employed.

Where the water content of the mix would be inadequate to ensure full hydration of the cement, water will be extracted from the foam and might lead to its disintegration. On the other hand whilst high w/c ratios do not significantly affect the porosity of the foamed concrete they do promote segregation and increase drying shrinkage (Gambhir, 2004).

### 4. Foamed Agent

Synthetic or protein-based foaming agents (surfactants) can be used to produce foam. Because of the possibility of degradation by bacteria and other organisms, natural protein based agents (i.e. fatty acid soaps) are rarely used to produce foamed concrete for civil engineering works. However research is underway on the use of protein-based agents for developing high strength, i.e... The chemical composition of a surfactant must be stable in the alkaline environment of concrete. Because all surfactants are susceptible to deterioration at low temperatures they should be stored accordingly. The properties of foamed concrete are critically dependent upon the quality of the foam. There are two types of foaming agent:

- I. Synthetic-suitable for densities of  $1000 \text{ kg/m}^3$  and above.
- II. Protein-suitable for densities from  $400$  to  $1600 \text{ kg/m}^3$ .

Protein-based foaming agents come from animal proteins out of horn, blood, bones of cows, pigs and other remainders of animal carcasses. Its surfactants might

therefore be best suited to the production of foamed concrete of relatively high density and high strength. Optimum performance of foam is commonly attained at a ratio of 1:25, but the optimum value is a function of the type of surfactant and the method of production (Gambhir, 2004).

### **2.2.6 Equipment**

The production of foamed concrete is a fairly easy process which does not involve any expensive or heavy machinery and in most cases uses equipment that is already available for normal concrete/mortar production. That include:

1. Normal concrete/mortar mixer or special mixers for foam concrete.
2. Foam Generator
3. Formwork (if producing pre- cast components)

### **2.2.7 Mixing procedures**

At first start with the sand and cement. Mix dry constituents for a few minutes and add water in stages and make sure the mixing is thorough (Mortar slurry preparation). Then, Preparation of pre-foamed by diluted the foam agent with water and extracted by using foam generator and air compressor. After that, add foam to the wet slurry and ensure foam has been completely mixed with the mortar. After mixing is completed check that the wet density of the foamed concrete is close to what is required.

There is no chemical reaction involved when the pre-foamed add into the cement mortar. Introduction of pores is achieved through mechanical means either by pre-formed foamed foaming (foaming agent mixed with part of mixing water) or mix foaming (foaming agent mixed with the mortar) (Yew,2007). Figure 2.1 shows manufacturing process of foamed concrete.

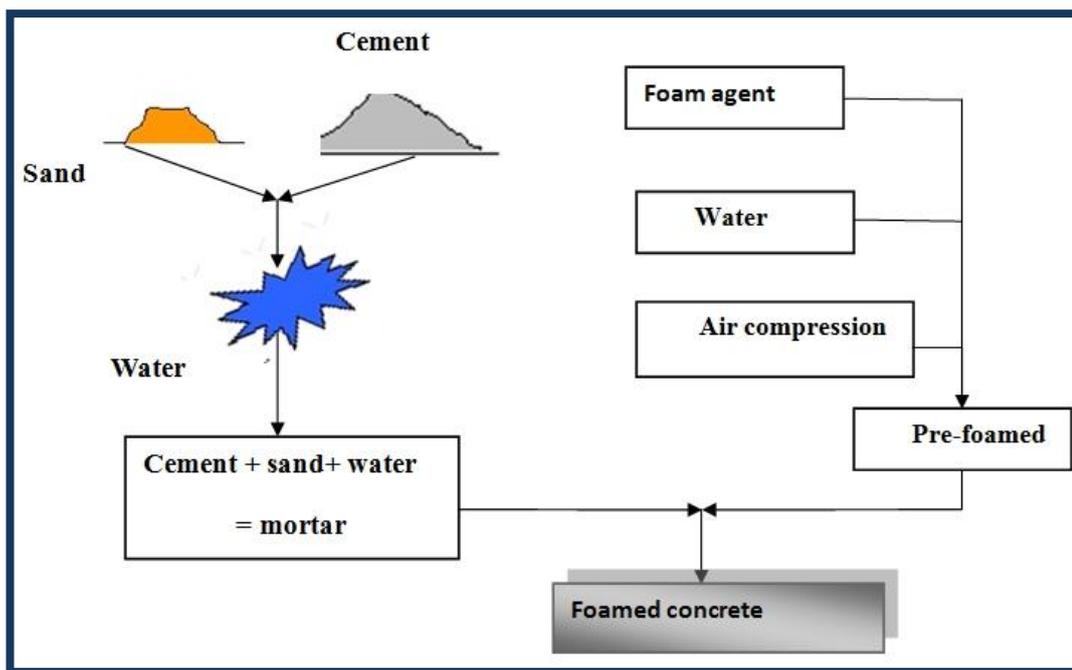


Figure 2.1: Manufacturing Process of Foamed Concrete

Pre-formed foaming is preferred to mix-forming technique due to the following advantages:

- (i) Lower foaming agent requirement
- (ii) A close relationship between amount of foaming agent used and air content of mix.

### 2.2.8 Curing of foamed concrete

Curing is a process of preventing freshly placed concrete from drying the first during the first day of its life to minimize any tendency to cracking and allow it to develop concrete strength. There are different methods of curing that affect the concrete properties as: water curing, sheet curing, membrane curing and air curing.

### **2.2.9 Benefit of foamed concrete**

Foamed contribute to the reduction of building dead weight thus resulting in more economic structural design. Production of more economic structural design will reduce the amount of material used and eventually cutting down the cost of construction project itself resulting in profit increase to the contractor. Besides that, other researchers added that the lightness of structure makes it easier to be transported and handled. In addition, it's also has a very low thermal conductivity that makes it an excellent fire protection property (John& Ban Choo, 2003). Some of advantages are explained below.

#### **2.2.9.1 Reduction of dead load**

- The reduction in foundation loads may result in smaller footing, fewer piles, smaller pile caps, and less reinforcing.
- Reduced dead loads may result in smaller supporting members (decks, beams, girder, and piers), resulting in major reduction in cost and result in larger space availability.
- Reduced dead load will mean reduced inertial seismic forces.
- Lighter and smaller pre-cast elements needing smaller and less expensive handling and transporting equipment.

#### **2.2.9.2 Saving material**

Environmental friendly sustainable material produced with least energy demand and reduces environmental pollution because some of it added with waste industrial products such as fly ash and no gravel are required to produce it save the earth source.

### **2.2.9.3 Speedier Constructions**

The absence of gravel coupled with the ball-bearing effect of the foam lends cellular concrete much higher consistency. No vibration is necessary when pouring cellular concrete into moulds/forms. It distributes evenly and fills all voids completely ensuring uniform density all over the material. This way full-height walls of a complete building (all internal and external walls) can be poured in-situ in one step, thus speeding-up the construction considerably.

### **2.2.9.4 Easy application**

- Foamed concrete can be pumped horizontally and vertically over significant distances without bleeding and segregation.
- Foamed concrete can be removed easily after hardening using normal equipment.
- Foamed concrete can be manufactured to specification of strength and in order to allow for any future removal that may be required during planned or emergency maintenance of utilities and services buried within the concrete.

### **2.2.9.5 Saving time and cost**

Foam concrete is an economically viable solution, particularly in large volume applications, where its use can also have an effect on other aspects of construction.

- From the above advantages it is clear that all lead to save money and time.
- Durability of foam concrete means lower maintenance costs.
- High volume equipment with rapid installation reduced installed unit costs
- Savings in manpower cost. Only a few workers are needed to produce foamed concrete for casting / pouring of panels, blocks or even complete walls for houses.

#### **2.2.9.6 Self leveling / Self compacting**

Foam concrete is naturally self-leveling and self-compacting, filling the smallest voids, cavities and seams within the pouring area.

In excavations with poor soils that cannot be easily compacted, foam concrete forms a 100% compacted foundation over the soft sub-soil. Compaction of conventional, granular backfill against retaining structures or deep foundations can cause damage or movement to the adjacent structure. In these situations, foam concrete with its reduced lateral loading is a safe solution.

#### **2.2.9.7 Thermal insulation**

Thermal conductivity depends on density, moisture content and ingredient of the material. As it is largely function of density, it does not really matter whether the product is moist cured or autoclaved as far as thermal conductivity is concerned. The amount of the pores and their distribution are also critical for thermal insulation.

Foamed concrete with a density of  $1200 \text{ kg/m}^3$  can produce a monolithic wall 5 times thinner and require 10 times lesser raw material (by weight ) and possesses 5 times superior insulation properties compared to conventional concrete. The amplitude-ratio and phase-displacement of a 15 cm thick wall with a density of  $1100 \text{ kg/m}^3$  causes the outside temperature of a building to take between 10-12 hours to reach inside. Such a duration, which is much longer than of conventional concrete wall, results in the foamed concrete being naturally air-conditioning .

Below is Table 2.1 in which thermal conductivity of foam concrete is compared with that of other materials.(Yun Bai,2003).

Table 2.1: thermal conductivity of foam concrete compared with other materials.  
(Yun Bai,2003)

Material	Density( kg/m <sup>3</sup> )	Thermal Conductivity W/mk
Marble	2700	2.9
Concrete	2400	1.3
Porous clay brick	2000	0.8
Foam concrete	1200	0.38
Foam concrete	1000	0.23
Foam concrete	800	0.18
Foam concrete	600	0.14

#### 2.2.9.8 Minimum investment

As conventional concrete and prefabrication plants may be used to produce foamed concrete, the only investment that would be necessary is in the inexpensive foam generator and foaming agent.

### 2.3 Properties of foamed concrete

Concrete can be distinguished onto two distinct phases; the fresh concrete and the hardened concrete. Three main properties should be controlled in fresh concrete; workability, consistency and cohesiveness. On the other hand, for hardened concrete, the strength is the most important property of concrete.

The physical properties of foamed concrete are closely related to its density, which can be regarded therefore as the main design criterion. Also it is depend on material mix and the way of mix.

Several studies investigated the physical and mechanical properties of foamed concrete cast in different densities and with or without fine aggregates in the mix. Because the density of cellular concrete may be varied over a wide range 320- 1920 kg/m<sup>3</sup>.

### 2.3.1 Density

Foamed concrete is manufactured by entrain relatively large volume of air into the cement paste by use the foam agent. High volume of air contents result in lower densities, higher porosity.

Density can be either in fresh or hardened state. Fresh density is required for mix design and casting control purposes. A theoretical equation for finding fresh density may not be applicable as there can be scatter in the results caused by a number of factors including continued expansion of the foam after its discharge, loss of foam during mixing. Many physical properties of foam concrete depend upon its density in hardened state. While specifying the density, the moisture condition needs to be indicated as the comparison of properties of foam concrete from different sources can have little meaning without a close definition of the degree of dryness.

According to Kearsley & Mostert (2005) from University of Pretoria have come out a mix design for foamed concrete mix, show the casting density clearly indicated that the mix design is suitable because the difference between the target densities aimed for and the actual measured are within 5%. cement content and foamed content should be established in designer.

Besides that, Jones & McCarthy (2005), from University of Dundee, show that it is difficult to design for a specified dry density as foamed concrete will desorbs between 50 and 200 kg/m<sup>3</sup> of the total mix water, depending on the concrete plastic density.

McCormick (2005) studied the effect of types of fine aggregate, aggregate gradation, type of foam and sand–cement ratio on the wet density of foam concrete and reported that wet densities within about 5% of the design densities can be achieved by using solid volume calculations.

### 2.3.2 Workability

Foamed concrete is a free-flowing, self-leveling material and should therefore be expected to give a collapse slump. Thus neither the slump test for normal weight concrete nor the flow test for concrete with a high slump is applicable. Therefore, the workability of foamed concrete can be measured using spreadability test. It is evaluated visually: in most cases it would not be difficult to spot when workability was unacceptably low.

The spread of the base mix should be between 115 and 140 mm for a PC/PFA mix and between 85 and 125 mm for a PC/sand mix. The workability of foamed concrete increases with increase w/c ratio and dosage of superplasticizer.

The effect of the type of surfactant on the properties of the foamed concrete has been investigated at the University of Dundee. The 'spreadability' of the various types of concrete are reasonably similar but, for otherwise identical mixes, concrete formed from a protein-based surfactant has a shorter flow time, which is indicative of a much lower plastic viscosity. However mixes formed from protein-based surfactants are prone to segregation, probably due to incompatibility of the surfactant with the superplasticizer.

### 2.3.3 Compressive strength

The strength of concrete originates from the strength of the hardening cement paste, which in turn, originates from hydration products. Compressive strength of foamed concrete is influenced by many factors such as density, age, curing method, component and mix proportion.

According to Kunhanandan Nambiar & Ramamurthy (2006), the following mixes were investigated by keeping the basic filler–cement ratio constant at 1:1 by weight. The foam required for three densities of foam concrete 800, 1250 and 1500 kg/m<sup>3</sup>. In the cement–sand–fly ash mixes 50% of the sand is replaced with fly ash

and in the cement–fly ash mixes all the sand is replaced with fly ash. For a given density, an increase in fly ash content of the mix results in increased strength. Foam concrete mixes based on fly ash as filler showed higher strength to density ratios than those based on sand for all density values. Figure 2.2 A & B show an increase in fineness of sand causes an increase in strength of foamed concrete. For a given density, the mix with fine sand resulted in higher strength than the mix with coarse sand and the variation is higher at higher density. This indicates that coarse sand causes clustering of bubbles to form irregular large pores. Thus it can be concluded that fine sand results in uniform distribution of bubbles and hence results in higher strength than coarse sand at a given density.

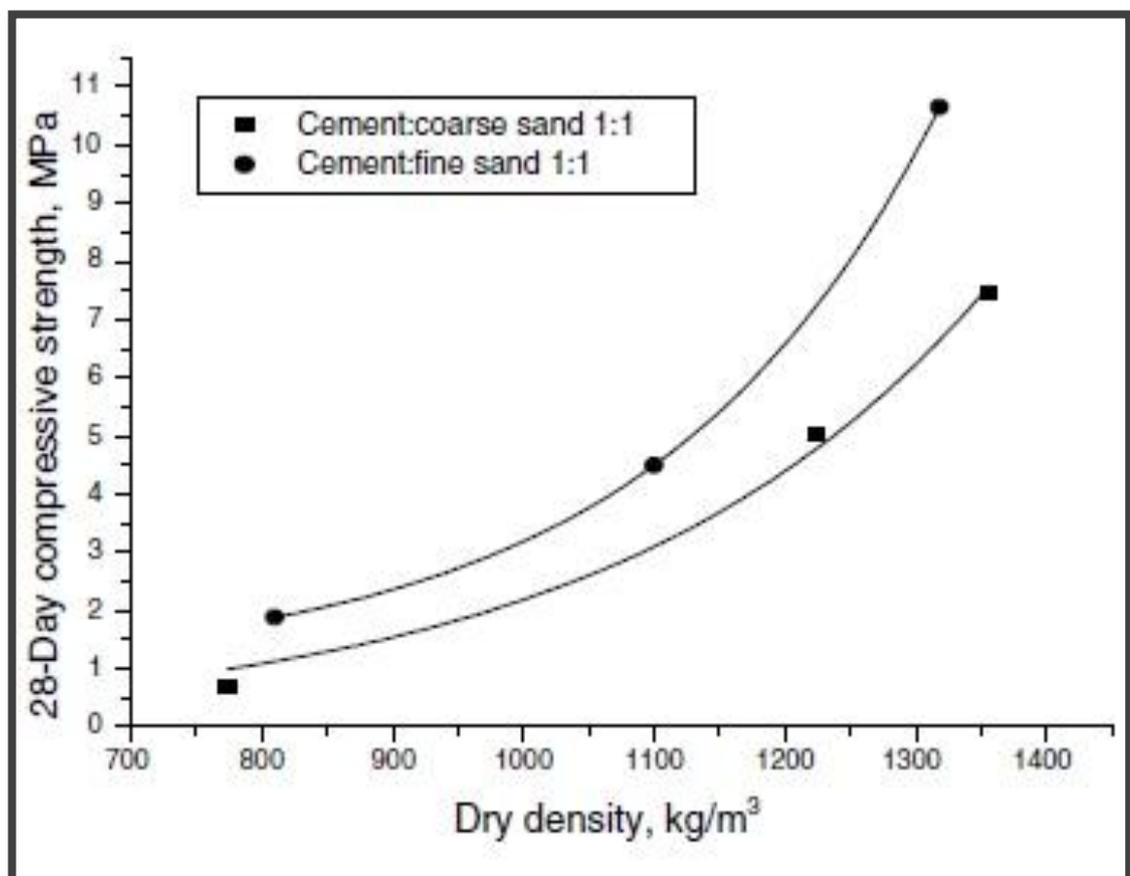


Figure 2.2.a: Strength Density Variation for Mixes with sand of different Fineness (Kunhanandan and Ramamurthy, 2006)

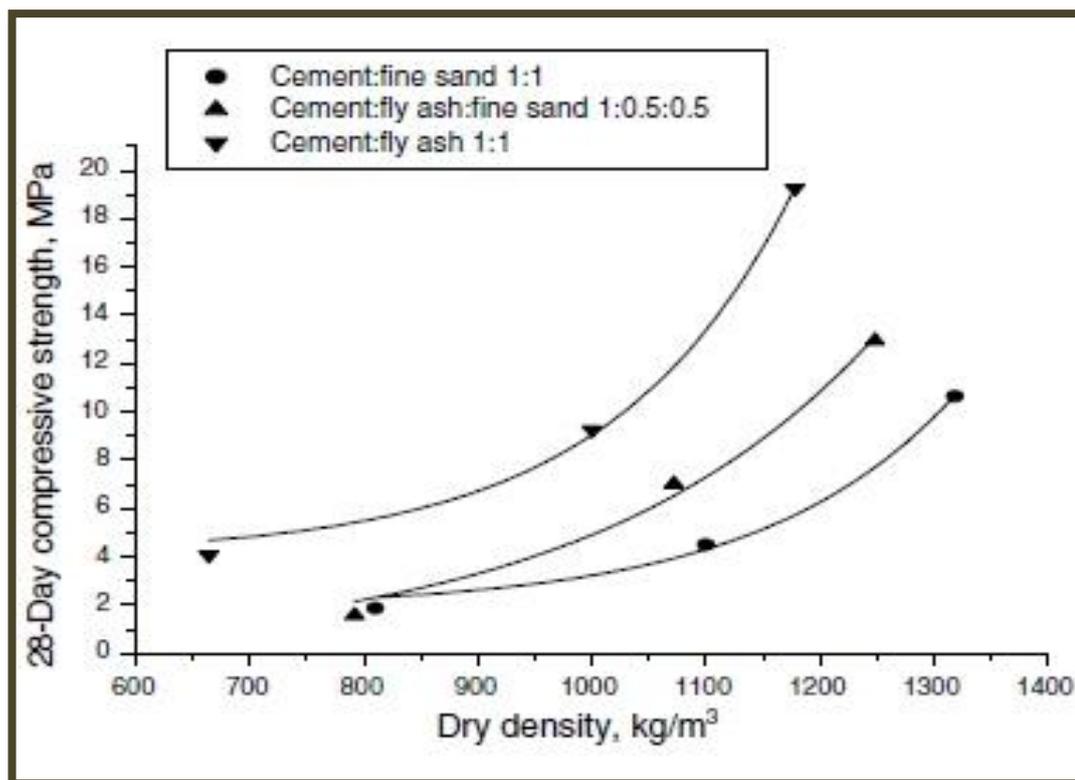


Figure 2.2.b: Strength Density Variation for Mixes with different Filler Type (Kunhanandan & Ramamurthy, 2006)

The compressive strength of foamed concrete reduces with decreasing density. For mixes of similar constituents, the density-strength relations should be reasonably similar. But, because constituents can vary widely, density is not necessarily a reliable indicator of strength or quality.

Kearsley & Wainwright (2001) investigate an exponential relationship between dry density and the 28-day compressive strength and there seems to be little difference between the strengths obtained from mixtures containing fly ash and those containing Pozz-fill. The mixtures containing no ash seem to have slightly higher strengths than the mixtures containing ash, confirming the fact that the early strength (up to 28 days) is reduced with high ash contents. However, it is significantly higher than those obtained by other researchers. The strength is shown in Figure 2.3 around 15 MPa for a dry density 1250 kg/m<sup>3</sup> is approximately double those published previously for other protein foams 7 Mpa for a dry density 1200 kg/m<sup>3</sup>.

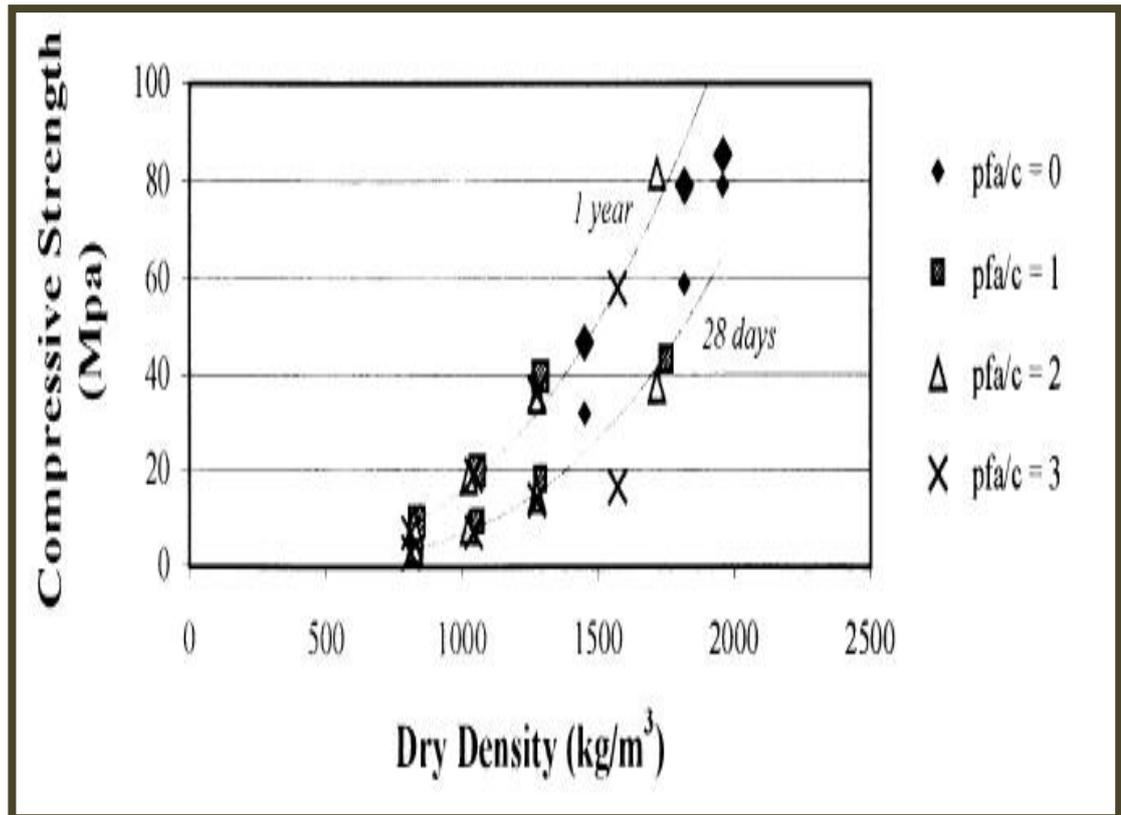


Figure 2.3: Compressive Strength at 28 days and 1 year as a Function of Dry Density (Kearsley and Wainwright ,2001)

They also study the effect of replacing large volumes of cement (*up to 75% by weight*) with both classified and unclassified fly ash on strength of foam concrete. Was reported that is up to 67% of the cement could be replaced with ungraded and graded fly ash without any significant reduction in strength. It is clear that replacing high proportions of cement with fly ash dose not significantly affect the long-term compressive strength of well cured foamed concrete. The study also shows that foamed concrete mixture with high ash contents might need a longer period of time to reach their ultimate strength. The strength could be higher that the ultimate strength that can be achieved using only cement.

The air-void distribution is one of the most important micro properties influencing strength of foam concrete. Foam concrete with narrower air-void distributions shows higher strength.

For dry density of foam concrete between 500 and 1000 kg/m<sup>3</sup>, the compressive strength decreases with an increase in void diameter. For densities higher than 1000 kg/m<sup>3</sup>, as the air-voids are far apart to have an influence on the

compressive strength, the composition of the paste determines the compressive strength, (Visagie & Kearsley 2002).

### 2.3.4 Water absorption

Kearsley & Wainwright (2001) investigate that, the water absorption of the paste and the foamed concrete mixtures (as expressed by the increase in mass as a percentage of dry mass) is plotted as a function of dry density as shows in Figure 2.4, from these results it could be concluded that because the mixtures with lower density absorb more water than higher densities. However, water absorption maybe expressed either as increase in mass per unit of dry mass.

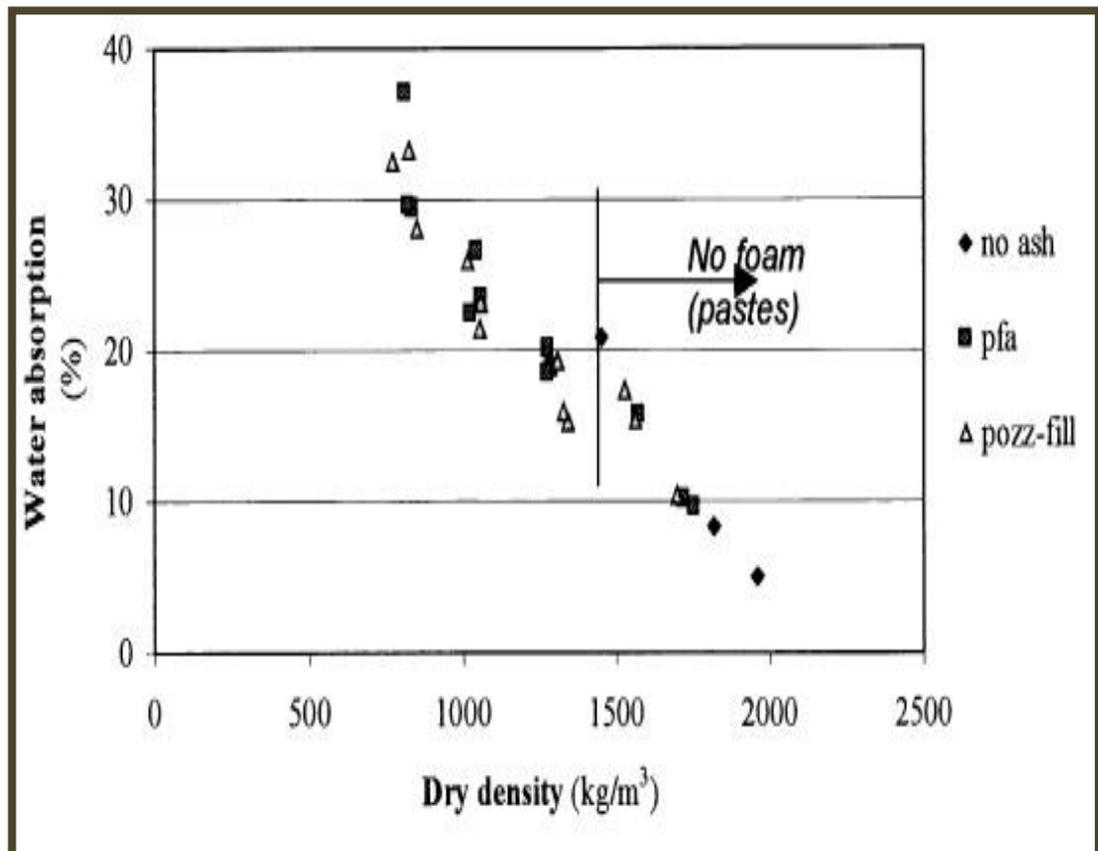


Figure 2.4: Effect of Dry Density on Percentage Water Absorption (Kearsley and Wainwright , 2001)

For the foamed concrete mixtures reported, there are significant differences in density (1000 to 1500 kg/m<sup>3</sup>) and expressing water absorption as the increase in mass per unit volume as shown in Figure 2.5. It is now apparent that that foamed concrete mixtures with low densities absorb only marginally more water than those with higher densities. It is also apparent that the cement paste mixture containing no ash (w/c=0.6) absorbs more water than any of the foamed concrete mixtures. It can also be seen that there is a trend of increased absorption with decreasing density for all mixtures but the increase absorption is much more significant in the paste (no foam) mixtures than in the foamed concrete mixtures.

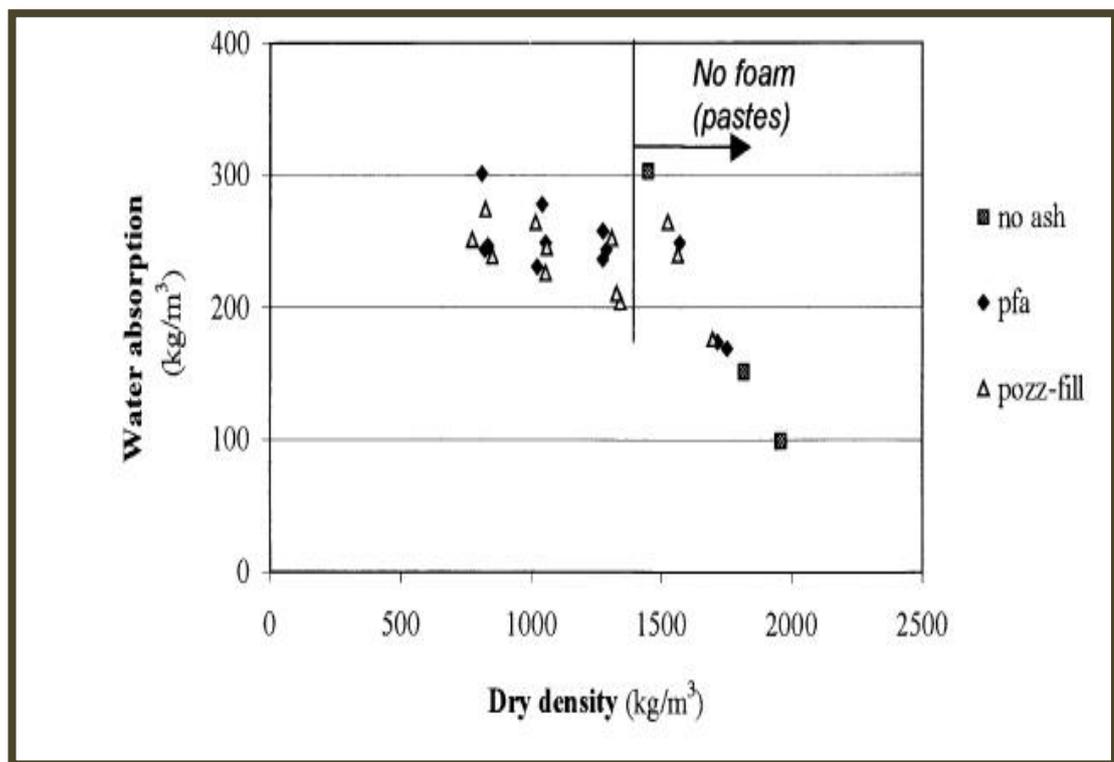


Figure 2.5: Effect of Dry Density on Water Absorption (Kearsley and Wainwright 2001)

According to Kunhanandan Nambiar & Ramamurthy (2006) show that the water absorption of foam concrete is observed to decrease with increase density. In comparison to cement–sand mixes, cement–fly ash mixes showed relatively higher water absorption as shown in Figure 2.6.

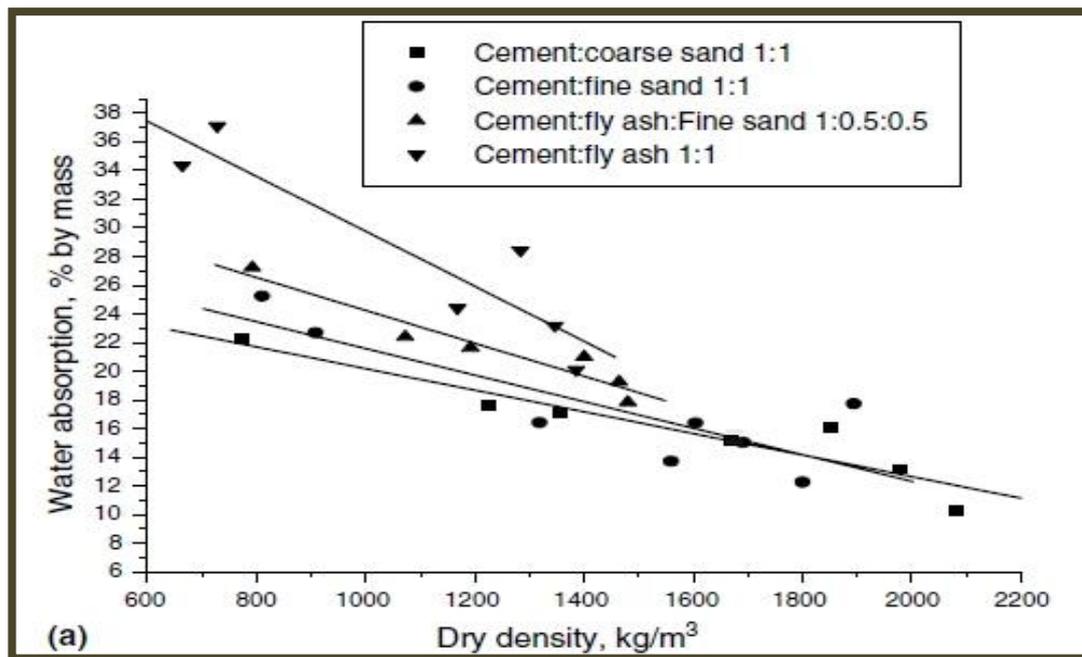


Figure 2.6: Variation of Water Absorption with Different Dry Density and Mixes (Kunhanandan Nambiar and Ramamurthy 2006)

### 2.3.5 Dry shrinkage

The mechanisms of concrete shrinkage, shrinkage of concrete consists of plastic shrinkage, autogenously shrinkage (a process known as self-desiccation), drying shrinkage, and carbonation shrinkage. Autogenously shrinkage is the consequence of withdrawal of water from the capillary pores by the anhydrous cement particles. Most of the autogenously shrinkage will take place at the early age of hydration of cement.

However, for concrete mixtures with a very low  $W/IC$  ratio, this procedure may last longer if moisture is available. Plastic shrinkage and drying shrinkage are caused by withdrawal of water from concrete under the condition of humidity gradient between the interior of concrete and air. These are the two main factors contributing to cracking of concrete at early age.

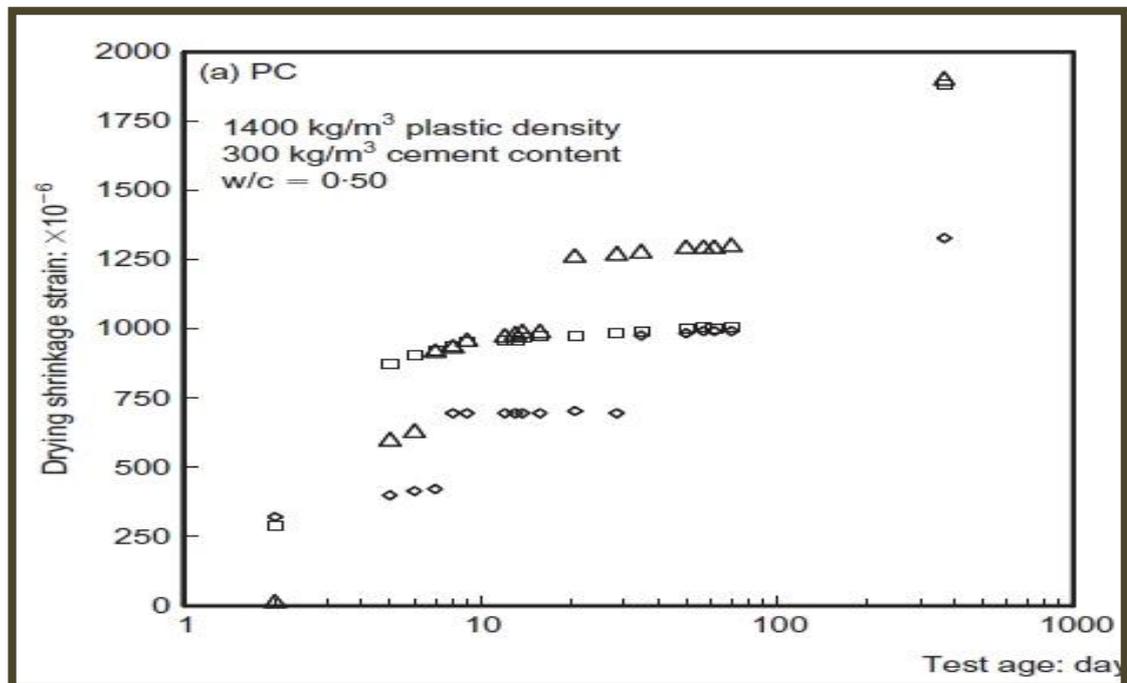
Foam concrete possesses high drying shrinkage due to the absence of aggregates, i.e., up to 10 times greater than those observed on normal weight concrete. The higher values for foamed concrete can be attributed to its (relatively)

high cement content, its high water content and the lack of coarse aggregate in the mix. The amount of drying shrinkage tends to increase with increasing foam content (i.e. with decreasing density of the concrete) and with increasing temperature.

According to McGovern (2000), shrinkage usually occurs within 20 days or so of casting.

In study conducted by Jones & McCarthy (2005), of foamed concrete mixes with the different fine aggregate types was consistent throughout with 100% FA coarse, 50% FA coarse, 50% sand and 100% sand in decreasing order of drying shrinkage strains. This trend was also reflected in the mass loss measurements, which were greater for the FA coarse than the sand foamed concretes. Overall, for the  $1400 \text{ kg/m}^3$  plastic density concretes examined, drying shrinkage strains between  $940 \times 10^{-6}$  and  $1900 \times 10^{-6}$  were observed after 12 months. The FA coarse mixes exhibited the largest shrinkage due to higher actual mix water quantities (at equal w/c ratio) and consequently the largest volume of paste than the equivalent sand specimens.

However, it is possible that the air bubbles also provide a degree of volume stability to the cementations matrix. As can be seen in Figure 2. 7.A& B, when 30% FA fine was used with PC, drying shrinkage strains were up to 2.6 times smaller on the  $1400 \text{ kg/m}^3$  specimens at a given test age.



(A)

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