

MECHANICAL AND PHYSICAL PROPERTIES OF FLY ASH FOAMED CONCRETE

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ABSTRACT

Foamed concrete has become most commercial material in construction industry. Fly ash is receiving more attention now since their uses generally improve the properties of blended cement concrete, cost saving and reduction of negative environmental affects. The physical and mechanical properties of foamed concrete differ according to a different type of mixture and its composition. Therefore, this research investigates physical and mechanical properties of fly ash foamed concrete. Fly ash was used as fine aggregate. Six series of fly ash foamed concrete for target densities (1000, 1100,1200,1300,1400 and 1500 kg/m³) with constant cement to fly ash ratio (1:1.5) and cement to water ratio (1:0.65) by weight were prepared and tested. Tests were conducted to study physical properties (work ability, water absorption, drying shrinkage and carbonation) and mechanical strengths properties (compressive, splitting tensile and flexural strengths). Three types of specimens (cube, cylinder and prism) were used in different quantity and different purposes. The specimens of drying shrinkage test were opened after one day but, others specimens were de-moulded after three days and subjected to air curing under room temperature. As result, the findings from this project are very encouraging towards the use of fly ash foamed concrete density of 1100 and 1200 kg/m³ in block application due to its compressive strength (3.7 – 6.7 MPa) whereas density of 1300, 1400 and 1500 kg/m³ in structural application due to its high compressive strength (10 – 18.8 MPa) and moderate water absorption that was below 10%. It was also found that the physical properties of fly ash foamed concrete are high drying shrinkage between -666 to -1022 micro strain, high water absorption for density less than 1300 kg/m³, higher workability (115 -180 mm diameter) and high carbonation depth that make it a good breathable material that removes carbon dioxide from our environment. Lastly comparative analyses were done to determine the relationships between the various mechanical properties parameters of the fly ash foamed concrete, namely the compressive strength, flexural strength, splitting tensile strength and mathematical equations were derived.

ABSTRAK

Konkrit berbusa merupakan salah satu bahan yang berkomersial tinggi dalam industri pembinaan. Abu terbang semakin mendapat perhatian di mana penggunaannya dapat meningkatkan sifat-sifat konkrit, menjimatkan kos dan mengurangkan kesan negatif kepada alam sekitar. Sifat fizikal dan mekanikal konkrit berbusa adalah berlainan bergantung kepada nisbah campuran bancuhan. Oleh itu, penyelidikan ini bertujuan menyiasat sifat fizikal dan mekanikal konkrit berbusa abu terbang. Abu terbang digunakan sebagai agregat halus. Enam siri konkrit berbusa dengan ketumpatan jangkaan (1000, 1100, 1200, 1300, 1400 and 1500 kg/m³) dengan nisbah simen terhadap abu terbang dan nisbah simen terhadap air (dalam berat) yang tetap iaitu masing-masing 1:1.5 dan 1:0.65 telah disediakan dan diuji. Ujian telah dilakukan untuk mengkaji sifat fizikal (kebolehkerjaan, penyerapan air, pengecutan kering dan pengkarbonatan) dan sifat kekuatan mekanikal (kekuatan mampatan, tegangan belahan dan lenturan). Tiga jenis spesimen (kiub, silinder dan prisma) telah digunakan dengan bilangan yang berbeza dengan tujuan yang berlainan. Spesimen untuk ujian pengecutan kering dibuka selepas satu hari, manakala spesimen yang lain telah dibukakan daripada acuan selepas tiga hari dan kemudian diawetkan secara udara dalam suhu bilik. Keputusan daripada kajian ini menunjukkan konkrit berbusa abu terbang dengan ketumpatan 1100 dan 1200 kg/m³ sesuai digunakan dalam blok dengan kekuatan mampatannya 3.7 – 6.7 MPa, dan ketumpatan 1300, 1400 dan 1500 kg/m³ di dalam penggunaan struktur disebabkan kekuatan mampatan yang lebih tinggi iaitu antara 10 – 18.8 MPa dengan penyerapan air yang sederhana kurang daripada 10%. Keputusan juga menunjukkan sifat fizikal konkrit berbusa yang mempunyai pengecutan kering yang tinggi antara 666 – 1022 micro strain, penyerapan air yang tinggi untuk ketumpatan yang kurang daripada 1300 kg/m³, kebolehkerjaan yang tinggi (115 – 180 mm diameter) dan pengkarbonatan yang tinggi membolehkannya berpotensi sebagai bahan bernafas yang dapat mengurangkan karbon dioksida daripada udara. Hubungan secara matematik antara pelbagai sifat mekanikal untuk konkrit berbusa abu terbang iaitu kekuatan mampatan, kekuatan lenturan, kekuatan tegangan belahan telah diterbitkan pada akhir kajian ini.

CONTENTS

	TITLE	I
	DECLARATION	II
	ACKNOWLEDGEMENT	III
	ABSTRACT	IV
	ABSTRAK	V
	CONTENTS	VI
	LIST OF TABLES	IX
	LIST OF FIGURES	X
	LIST OF SYMBOLS	XIII
	LIST OF APPENDIX	XIV
		1
CHAPTER 1	INTRODUCTION	
	1.1 Background	1
	1.2 Problem Statement	2
	1.3 Objectives of Study	3
	1.4 Significance of study	4
	1.5 Scope of Study	4

CHAPTER 2	LITERATURE REVIEW	5
2.1	Introduction	5
2.2	Overview of foamed concrete	8
2.2.1	Material of foamed concrete	8
2.2.2	Foamed concrete manufacturing	10
2.2.3	Curing	13
2.3	Properties of foamed concrete	14
2.3.1	Physical properties of foamed concrete	15
2.3.2	Mechanical properties of foamed concrete	23
2.4	Advantages of foamed concrete	27
2.5	Disadvantages of foamed concrete	30
2.6	Details of particular projects	30
2.6.1	Approach embankment, Colchester	30
2.6.2	Bridge deck, North Wales	31
2.6.3	Kingston bridge	31
2.6.4	Access road, canary wharf	32
CHAPTER 3	METHODOLOGY	33
3.1	Introduction	33
3.2	Material preparation	35
3.2.1	Water	35
3.2.2	Cement	35
3.2.3	Fly ash	36
3.2.4	Foaming agent	37
3.3	Experimental work	38
3.3.1	Composition of mixture	38
3.3.2	Batching the material	39
3.3.3	Foamed concrete specimens	40
3.4	Tests on fresh/ hardened concrete	42
3.4.1	Tests on fresh concrete	42

3.4.2	Tests on hardened concrete	43
3.5	summary	51
CHAPTER 4	DATA AND ANALYSIS	52
4.1	Introduction	52
4.2	Fresh concrete properties	52
4.2.1	Workability	52
4.3	Hardened concrete properties	54
4.3.1	Compressive strength for fly ash foamed concrete specimens	54
4.3.2	Splitting tensile strength for fly ash foamed concrete specimens	56
4.3.3	Flexural strength (Modulus of Rupture) of fly ash foamed concrete	57
4.3.4	Water absorption of concrete	59
4.3.5	Carbonation depth	61
4.3.6	Drying shrinkage	62
CHAPTER 5	RESULTS AND ANALYSIS	67
5.1	Introduction	67
5.2	Relationship and discussions on properties of concrete	67
5.2.1	Relationship between workability and compressive strength	68
5.2.2	Relationship between density, age and compressive strength	69
5.2.3	Relationship between compressive strength, flexural and splitting tensile strength	70
CHAPTER 6	CONCLUSIONS AND RECOMMENDATIONS	76
6.1	Conclusions	76
6.2	Recommendations	78
	REFERENCES	79
	APPENDIX A-I	83-106

LIST OF TABLES

3.1	Chemical compound of ordinary Portland cement	36
3.2	Chemical components of fly ash	37
3.3	Summaries of the specimens type and quantity	40
4.1	Spread diameter values for fly ash foamed concrete	53
4.2	Compressive strength for fly ash foamed concrete	55
4.3	Splitting tensile strength of fly ash foamed concrete	56
4.4	Flexural strength of fly ash foamed concrete	58
4.5	Water absorption percentage of all fly ash foamed concrete samples	59
4.6	Carbonation depths for all foamed concrete	61
4.7	Dry shrinkage for all fly ash foamed concrete	63
5.1	Flexure and compressive strengths ratio on 28 th day	70
5.2	Splitting tensile and compressive strengths ratio	71

LIST OF FIGURES

2.1	Basic Form Lightweight Concrete (Newman & Ban, 2003)	8
2.2	Manufacturing process of foamed concrete	13
2.3	Effect of Dry Density on Percentage Water Absorption (Kearsley & Wainwright , 2001)	17
2.4	Effect of Dry Density on Water Absorption (Kearsley and Wainwright 2001)	18
2.5	Variation of Water Absorption with Different Dry Density and Mixes(Kunhanandan Nambiar and Ramamurthy 2006)	19
2.6	: Influence of FA Coarse and FA Fine on Early Age Drying Shrinkage of Foamed Concrete (Jones and McCarthy, 2005)	21
2.7	Carbonation Resistance of Foamed Concrete (Brady, 2001)	22
2.8	: Effect of Fines in Carbonation Resistance of Foamed Concrete (Jones and McCarthy, 2005)	23
2.9 a	Strength Density Variation for Mixes with sand of different Fineness (Kunhanandan and Ramamurthy, 2006)	24
2.9 b	Strength Density Variation for Mixes with different Filler Type (Kunhanandan & Ramamurthy, 2006)	25
2.10	Compressive Strength at 28 th day and 1 year as a Function of Dry Density (Kearsley & Wainwright, 2001)	26
3.1	Steps of experiment	34
3.2	The Foam Generator and Concrete Mixer	40
3.3	Cured Samples Foamed Concrete in the Lab	41

3.4	Spreadability test	43
3.5	The Universal testing Machine	44
3.6	Cube under Compression Strength test Processes	44
3.7	Flexural Strength test (Centre-point loading)	45
3.8	Beam after Flexural Strength test	46
3.9	Cylinder under Splitting Tensile Strength test	47
3.10	Equipments for Water Absorption test	48
3.11	Instrument for determining drying shrinkage	49
3.12	carbonation test	50
4.1	Workability all fly Ash foamed concrete	53
4.2	Compressive strength for fly ash foamed concrete	55
4.3	Splitting tensile strength of fly ash foamed concrete	57
4.4	Flexural strength of fly ash foamed concrete	58
4.5	Water absorption percentage for all fly ash foamed concrete	60
4.6	Carbonation depths for all fly ash foamed concrete	62
4.7	Drying shrinkage for all fly ash foamed concrete mixes	66
5.1	Relationship between workability and compressive strength	68
5.2	Effect density and age on compressive strength	69
5.3	Relationship between compressive strength and tensile strength	73
5.4	Relationship between compressive strength and tensile strength (In power's law)	74

5.5	Relationship between compressive strength and flexural strength	74
5.6	: Relationship between compressive strength and flexural strength (In power's law)	75

LIST OF SYMBOLS AND ABBREVIATIONS

Φ	-	Diameter of cylinder
mm	-	Millimeter
Kg	-	Kilogram
N	-	Newton
m	-	Meter
ml	-	Milliliter
MR	-	Modulus of Rupture
μm	-	Micro Strain
M1	-	Fly ash foamed concrete density 1000 kg/m ³
M2	-	Fly ash foamed concrete density 1100 kg/m ³
M3	-	Fly ash foamed concrete density 1200 kg/m ³
M4	-	Fly ash foamed concrete density 1300 kg/m ³
M5	-	Fly ash foamed concrete density 1400 kg/m ³
M6	-	Fly ash foamed concrete density 1500 kg/m ³
OPC	-	Ordinary Portland Cement
ACI	-	American Concrete Institute

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	The Experimental Results for (M1)	83
B	The Experimental Results for (M2)	87
C	The Experimental Results for (M3)	91
D	The Experimental Results for (M4)	95
E	The Experimental Results for (M5)	99
F	The Experimental Results for (M6)	103

CHAPTER 1

INTRODUCTION

1.1 Background

Concrete is one of the most widely used construction materials in the world today. It is made by mixing small pieces of natural stone (called aggregate) together with a mortar of sand, water, Portland cement and possibly other cementations materials.

Properly designed and constructed, concrete structures compare favourably with regard to economy, durability and functionality with structures made from other structural materials, such as steel and timber. One of the advantages of concrete is that it is readily moulded into virtually any required shape. Concrete is the preferred construction material for a wide range of buildings, bridges and civil engineering structures (Frank, 1989).

It is the second most widely consumed substance on earth, after water. Therefore, in concrete construction, self-weight represents a very large proportion of the total load on the structure, and there are clearly considerable advantages in reducing the density of concrete. The chief of these are the use of smaller sections and the corresponding reduction in the size of foundations .Furthermore, with lighter concrete the form work need withstand a lower pressure than would be the case with ordinary concrete , and also the total weight of materials to be handled is reduced with a consequent increase in productivity, light weight concrete also gives better thermal insulation than ordinary concrete, the practical range of densities of lightweight concrete is between 300 and 1850 kg/m³, the weight reduction of a concrete structure would require less structural steel reinforcement.

There are several ways to reduce the concrete density include using lightweight aggregates, foam, high air concrete and no-fine concrete(Liew, 2005).

Foamed concrete is one of the lightweight concrete and it's referred to cellular material which is consisting of Portland cement, fine aggregate, water, foaming agent and compressed air.

Foamed concrete is used for a variety of applications, ranging from thermal insulation and fire protection to void-filling and building elements with successively increasing density and strength requirements, such as, an insulating fill in fire walls or other precast elements, a replacement for soils and backfills, and the construction of cast-in-place piles.

Foamed concrete is similar to conventional concrete as it uses the same ingredients. However, foamed concrete is differing from conventional concrete in that the use of aggregates in the former is eliminated. In commercial practice, the sand is replaced by pulverized fuel ash or other siliceous material, cases product different Physical and mechanical characteristics of foam concrete by various mix component and designs.

Fly ash is a residual material of energy production using coal, which has been found t have numerous advantages for use in the concrete reduced permeability, increased ultimate strength, reduced bleeding, better surface finish and reduced heat of hydration. For several years it has been used in varying proportions and compositions in concrete. Research indicates that there are still additional benefits to be gained if the concrete industry can further optimize its use in concrete. Therefore, this project investigates the physical and mechanical properties of fly ash foamed concrete (American concrete institute, 1996).

1.2 Problem statement

The concrete industry is currently consuming natural aggregates at a rate of approximately 8 billion tones every year. Also, Portland cement is widely used in concrete industry since many decades ago; however it releases green house gases, carbon dioxide (CO₂), into the atmosphere during its manufacture, (Malhotra,

2002). Also, the cement manufactures to consume a large amount of energy this is about 7,600,000 KJ per tone or 1.1 ton of cement (Naik & Shiw, 1996). Geopolymer technology is one of the new technologies attempted to reduce the use of Portland cement in concrete, and look for environmental friendly.

Fly ash reacts with alkaline solutions to form a cementation material; fly ash geopolymer based; does not emit carbon dioxide into the atmosphere. The use of fly ash is one of the possibilities to produce artificial aggregate. This option allows mitigation of shortages problem of natural resources as well as providing a productive use for industrial waste. To encourage usage of fly ash foamed concrete there is a need to know the properties of fly ash foamed concrete in Malaysian environment situation.

1.3 Objectives of study

This project aims to achieve the following:

- i. To determine physical properties (workability, water absorption, carbonation depth and drying shrinkage) of fly ash foamed concrete.
- ii. To investigate mechanical strengths (compressive, splitting tensile and flexural strengths) of fly ash foamed concrete.
- iii. To establish correlation of the mechanical strengths for fly ash foamed concrete.

1.4 Significance of study

The significance of the study is to analyse the fly ash foamed concrete properties of concrete in the fresh and hardened states. In the fresh state, workability and workability will be determined. While in the hardened stage, compressive strength, water absorption and carbonation will be investigated. Also the strength of the model will be developed.

1.5 Scope of study

In this study six types of foamed concrete mixtures of different density ranging from 1000 to 1500 kg/m³ were prepared. The raw materials of foamed concrete consist of OPC, fly ash and foam. Hardened specimens such as 100 mm cube, 100x100x500 prism and 150mm diameter x 300mm length cylinder were prepared and tested to study the physical and mechanical properties of fly ash foamed concrete. Meanwhile, workability test using spreadability was used to conduct foamed concrete during plastic stage. All can summary in points as:

- i.** preparation of fly ash foamed concrete with density range from 1000 to 1500 Kg/m³.
- ii.** Empirical study of properties of fly ash foamed concrete.
- iii.** Analytical study to establish strength model of fly ash foamed concrete.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Lightweight concrete can be defined as a type of concrete which includes an expanding agent in that it increases the volume of the mixture while giving additional qualities such as nailability and lessened the dead weight. It is lighter than the conventional concrete. Lightweight concrete maintains its large voids and not forming laitance layers or cement films when placed on the wall. Lightweight concrete can be prepared either by injecting air in its composition or it can be achieved by omitting the finer sizes of the aggregate or even replacing them by a hollow, cellular or porous aggregate. Particularly, lightweight concrete can be categorized into three groups.

There are three type of light weight aggregate concrete are illustrated schematically in Figure 2.1.

i). No-fines concrete

No-Fines concrete is a mixture of cement, water and a single sized coarse aggregate combined to produce a porous structural material. It has a high volume of voids, which is the factor responsible for the lower strength and its lightweight nature. No-fines concrete has many different names including zero-fines concrete, pervious concrete and porous concrete. . The coarse aggregate should preferably be a single-size material (nominal maximum sizes 10 mm and 20 mm being the most common).

However, blended aggregates (10 and 7 mm; and 20 and 14 mm) have been found to perform satisfactorily.

This form of concrete has the ability to allow water to permeate the material which reduces the environmental problems associated with asphalt and conventional concrete pavements. The most common application of no-fines concrete is in low traffic volume areas, for example: parking lots, residential roads, driveways and footpaths.

ii). Lightweight aggregate concrete

The low specific gravity is used in this lightweight concrete instead of ordinary concrete. The lightweight aggregate can be natural aggregate such as pumice, scoria and all of those of volcanic origin and the artificial aggregate such as expanded blast-furnace slag, vermiculite and clinker aggregate.

The lightweight aggregate concrete can be divided into two types according to its application. One is partially compacted lightweight aggregate concrete and the other is the structural lightweight aggregate concrete. The partially compacted lightweight aggregate concrete is mainly used for two purposes that are for precast concrete blocks or panels and cast in-situ roofs and walls. The main requirement for this type of concrete is that it should have adequate strength and a low density to obtain the best thermal insulation and a low drying shrinkage to avoid cracking. Structurally lightweight aggregate concrete is fully compacted similar to that of the normal reinforced concrete of dense aggregate. It can be used with steel reinforcement as to have a good bond between the steel and the concrete (Mohd & Samidi, 1997).

iii). Aerated concrete

Aerated concrete does not contain coarse aggregate, and can be regarded as an aerated mortar. Typically, aerated concrete is made by introducing air or other gas into a cement slurry and fine sand. In commercial practice, the sand is replaced by pulverized fuel ash or other siliceous material, and lime maybe used instead of cement.

Classification of aerated concrete can be non-autoclaved (NAAC) or autoclaved (AAC) based on the method of curing, whereas Aerated concrete is classified into (gas concrete) and (foamed concrete) based on the method of pore-formation (Mohd & Samidi, 1997).

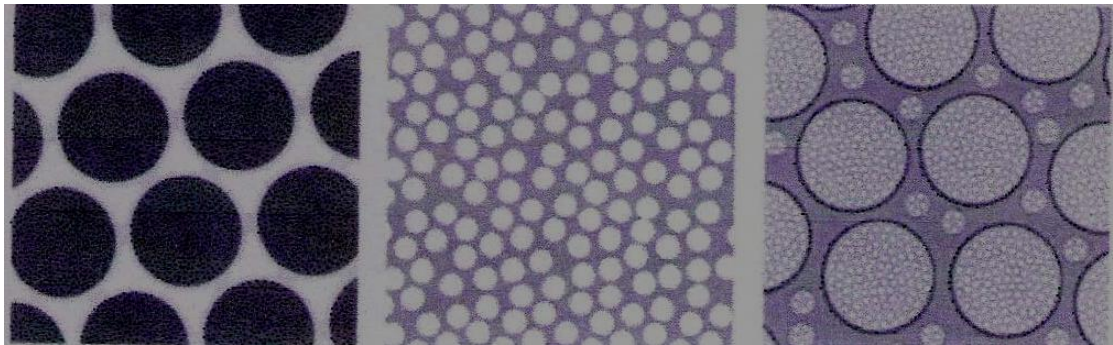
- **Gas-forming**

Chemicals are mixed into lime or cement mortar during the liquid or plastic stage, resulting in a mass of increased volume and when the gas escapes, leaves a porous structure. Aluminum powder, hydrogen peroxide/ bleaching powder and calcium carbide liberate hydrogen, oxygen and acetylene, respectively. Among these, aluminum powder is the most commonly used aerating agent. This is usually used in precast concrete factories where the precast units are subsequently autoclaved in order to produce concrete with a reasonable high strength and low drying shrinkage.

- **Foamed concrete:**

It is manufactured by entraining relatively large volumes of air into the cement paste by the use of a chemical foaming agent (Kearsley & Wainright, 2001). In other words, it is a mortar mix containing air voids that been produced by adding foaming agents which plays the role of creating pores within the concrete without chemically reacting to the cement. This is mainly used for in situ concrete suitable for insulation roof screeds or pipe lagging.

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



(a) No-fine aggregate (b) Aerated (c) Lightweight aggregate

Figure 2.1: Basic Form Lightweight Concrete (Newman & Ban, 2003)

2.2. Overview of foamed concrete

2.2.1 Material of foamed concrete

1. Foaming Agent

Foaming agents is also defined as air entraining agent. Air entraining agents are organic materials. When foaming agents added into the mix water it will produce discrete bubbles cavities which become incorporated in the cement paste. 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 kg/m^3 and above.
- ii). Protein-suitable for densities from 400 kg/m^3 to 1600 kg/m^3 .

Foams from protein-based have a weight of around 80 g/ liter. Protein-based foaming agents come from animal proteins out of horn, blood, bones of cows, pigs and other remainders of animal carcasses. This leads not only to occasional variations in quality, due to the differing raw materials used in different batches, but also to a very intense stench of such foaming agents.

Synthetic foams have a density of about 40 g/litter. Synthetic foaming agents are purely chemical products. They are very stable at concrete densities above 1000 kg/m³ and give good strength. Their shelf life is about 1 year under sealed conditions. Synthetic foam has finer bubble sizes compared to protein but they generally give lower strength foamed concrete especially at densities below 1,000 kg/m³ (Brady & Jones, 2001).

2. Cement

Based on BS 12:1996, ordinary Portland cement is usually used as the main binder for foamed concrete. Portland cement is a hydraulic cement that when mixed in the proper proportions with water, will harden under water (as well as in air). The basic ingredient for Portland cement consists of:

- i). Lime-rich materials, such as limestone, seashells, marl, and chalk that provided the calcareous components;
- ii). Clay, shale, fly ash, or sand to provided the silica and alumina;
- iii). Iron ore, iron containing shale, mill scale or similar material to provided the iron or ferriferous component.

3. Water

Water is once of the important material for the foamed concrete. The quality of the water must best on the BS3148. The criterion of portability of water is not absolute. Water with Ph 6 to 8 which not tested saline or brackish is suitable for use. Natural water that is slightly acidic is harmless, but water containing humic or other organic acids may adversely affect the hardening of concrete. The present of algae in the mixing water will result in air entrainment with consequent loss of strength. Hardness of water does not affect the efficiency of air-entraining admixtures. The use of the sea water as mixing water must be considered. Sea water has, typically, a total salinity of about 3.5 per cent. It can cause the long term-strength of the concrete become low. Sea water also contain a lot of chlorides it can cause corrosion for the reinforcement concrete. So the mixing water shall be clear and apparently clean (Neville & Brooks, 2001).

4. 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.

For sand Sach & Seifert (1999) 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. For practical reasons, most sands can only be used to produce foamed concrete having a dry density in excess of about 1200 kg/m^3 .

However, according to BS 3892: Part 1:1997 fly ash can be used as a partial or total replacement for sand to produce foam concrete with a dry density below about 1400 kg/m^3 . There are two general classes of fly ash can be defined, low calcium fly ash (FL) and high calcium fly ash (FH). FL is produced by burning anthracite or bituminous coal. FL is categorized as a normal pozzolan, a material consisting of silicate glass modified with aluminium and iron. The CaO content is less than 10%. While FH is produced by burning lignite or sub-bituminous coal, it can be categorized as cementitious material when CaO is greater than 20% or as cementitious and pozzolanic material when CaO varies between 10% to 20%. Therefore, fly ash is one of the major industrial by-products and utilization of it has great significance on economy and environment (Papadakis, 2000)

2.2.2 Foamed concrete manufacturing

Foamed concrete is a lightweight, free flowing material which is manufactured by adding foam, prepared by aerating a foaming agent solution, to cement paste or

cement mortar. Figure 2.2 shows the process of the manufacturing of the foamed concrete. The 3 basic methods of producing foamed concrete are:

1. Pre-foamed method
2. Inline system wet method.
3. Incline system dry method.

1. Pre-foamed method

The pre-foamed method involves half a load (normally 3m^3) or less, of base materials being delivered to site in a ready mix wagon, with the pre-foamed foam (either a wet or dry system) then injected directly into the back of ready mix wagon whilst it is on fast spin. The injection of the foam bulks the material up to a full load whilst lowering the density (Aldridge, 2005).

The various foaming agents used are detergents, resin soap, glue resins, saponin, and hydrolysed proteins. Normally, the hydrolyzed protein based foaming agent been employed in the produces of the pre-foamed concrete. Inside the generator, the agent is diluted with water to make a pre-foaming solution which is then forced at high pressure through the foaming lance. This produces uniform and stable foam which has a volume of about 20 to 25 times that of the pre-foaming solution. Batching of cement paste for adding the pre-foamed in to it to produced the foamed concrete. When batching of the cement paste a reaction of the cement paste will occur. The three major disadvantages of this method are:

1. The manufactured volume is governed by the size of the truck.
2. The quality of foamed concrete is reliant on the mixing action of the truck to blend the foam.
3. If the material is out of specification then the whole is rejected.

From experience it is known that some trucks mix better than others which can lead to large inconsistencies with both the density and consequently the yield of the foamed material. However if good reliable foam generators are used in conjunction with a modern fleet of truck mixers, and a correctly specified foamed concrete, then the results can be adequate (Aldridge, 2005).

Using this method of foamed concrete production is it using a wet or dry foam generating system, although still practiced, is generally on the decrease due in the main to the material inconsistency and the associated problems.

2. Inline system wet method.

Inclined system (wet method) has been driven in the main part by the need for both higher product quality control and a commercial requirement for lower density material. These systems incorporate the same type of foam generator and foaming chemicals as used in the pre-foam method, but differs in that it accepts wet base materials into an onboard hopper and adds the foam through a completely separate process altogether.

The base materials used in this method are generally wetter than the ones used in the pre-foam method but comprise of the same materials. These systems work by feeding the base material and the foam (dry type only) through a series of static inline mixers where the two components are mixed together. These mixers have the effect of blending the foam and the based materials together into a completely homogenized mix ensuring a completely repeatable mixing process along with a constant checking procedure via the continual on-board density monitor.

Another advantages over the ore-foam method is that due to the method of production the output volume is not governed by the size of the ready-mix wagon, so one 8 cubic meter delivery of base materials from a ready-mix supplier will produce 35 cubic meters of a 500kg/m^3 density foamed concrete. This is an extremely effective method of working, with truck movements reduced by 80% (Aldridge, 2005).

3. Incline system dry method

These inline systems in dry method are a relatively new development and are in the main operated in Europe although versions are gradually being accepted in the UK. They operate on a similar principal to the dry inline method but instead of accepting wet materials from ready-mix supplier they have dry materials loaded in on-board silo's and aggregate bins.

These materials can then be batched, weighed and mixed on-site as required via on-board mixers. Once blended the base mix is then pumped to a mixing chamber where the foam is then added in a similar way to the dry method. A major disadvantage is that they require large amounts of water at site (to mix the cement and aggregate together) they are then unsuitable for congested city centre or projects where water cannot be supplied at suitable rates.

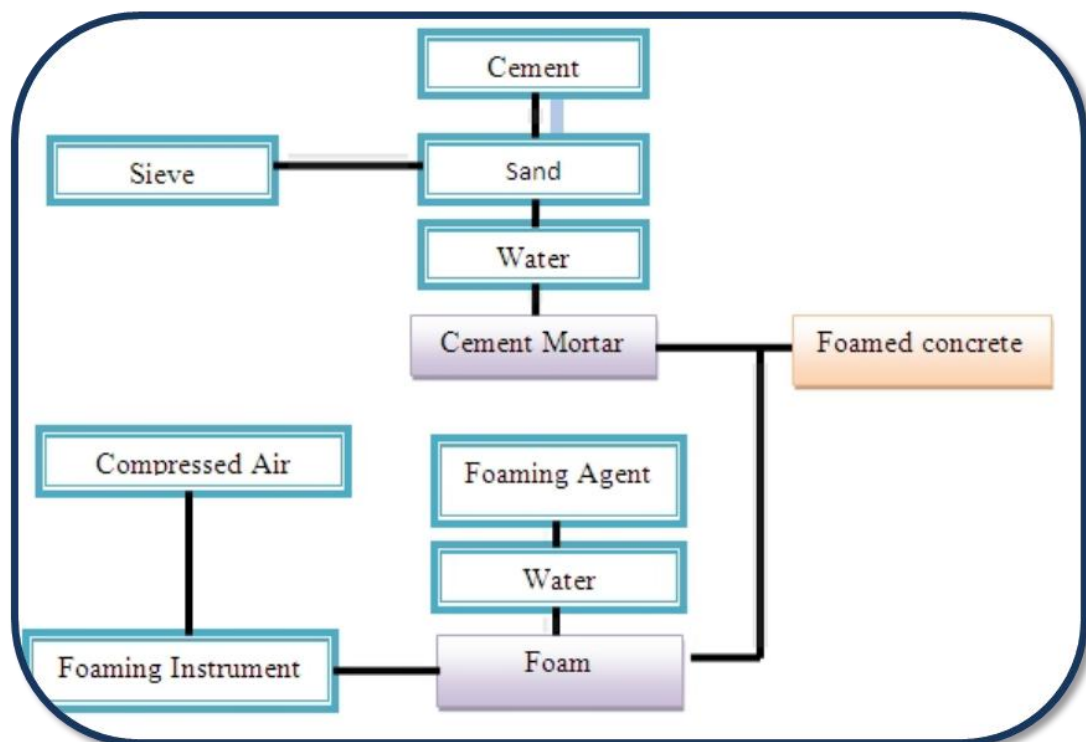


Figure 2.2: Manufacturing process of foamed concrete

2.2.3 Curing

As for all materials, the performance of concrete is determined by its microstructure. Its microstructure is determined by its composition, its curing conditions, and also by the mixing method and mixer conditions used to process the concrete. Curing is used in the construction of structure such as bridges, retaining walls, pump house, large slabs and structured foundation. 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. Curing begins after placement and finishing so that the concrete may develop the desired strength and hardness. To obtain good quality concrete, the process to preventing the loss of the moisture from the concrete whilst maintaining a satisfactory temperature regime is very important (Narayanan & Ramamurthy, 2000). According to British Standard for the structural use of concrete the intention of curing is to protect concrete against:

1. Premature drying out, particularly by solar radiation and winds (plastic shrinkage)
2. Leading out by rain and flowing water
3. Rapid cooling during first few after placing.
4. High internal thermal gradients
5. Low temperature or frost
6. Abrasion and impact which may disturb the concrete and interfere with bond to reinforcement.

There are different methods of curing that can be pointed out as:

1. Water curing
2. Sheet curing /blanket curing
3. Membrane curing
4. Air curing

This is probably the easiest and most popular method of curing. It is a slow, but acceptable system which enables a turnaround of moulds every 24 hours on average, depending on the ambient temperature.

2.3 Properties of foamed concrete

Concrete can be distinguished into 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/m³.

2.3.1 Physical properties of foamed concrete

2.3.1.1 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 foamed 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 foamed 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/m³ 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 foamed concrete and reported that wet densities within about 5% of the design densities can be achieved by using solid volume calculations.

2.3.1.2 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 spread ability 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 reasonable 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 concrete from protein-based surfactants are prone to segregation, probably due to incompatibility of the surfactant with the superplasticizer.

2.3.1.3 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 2.3, 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.

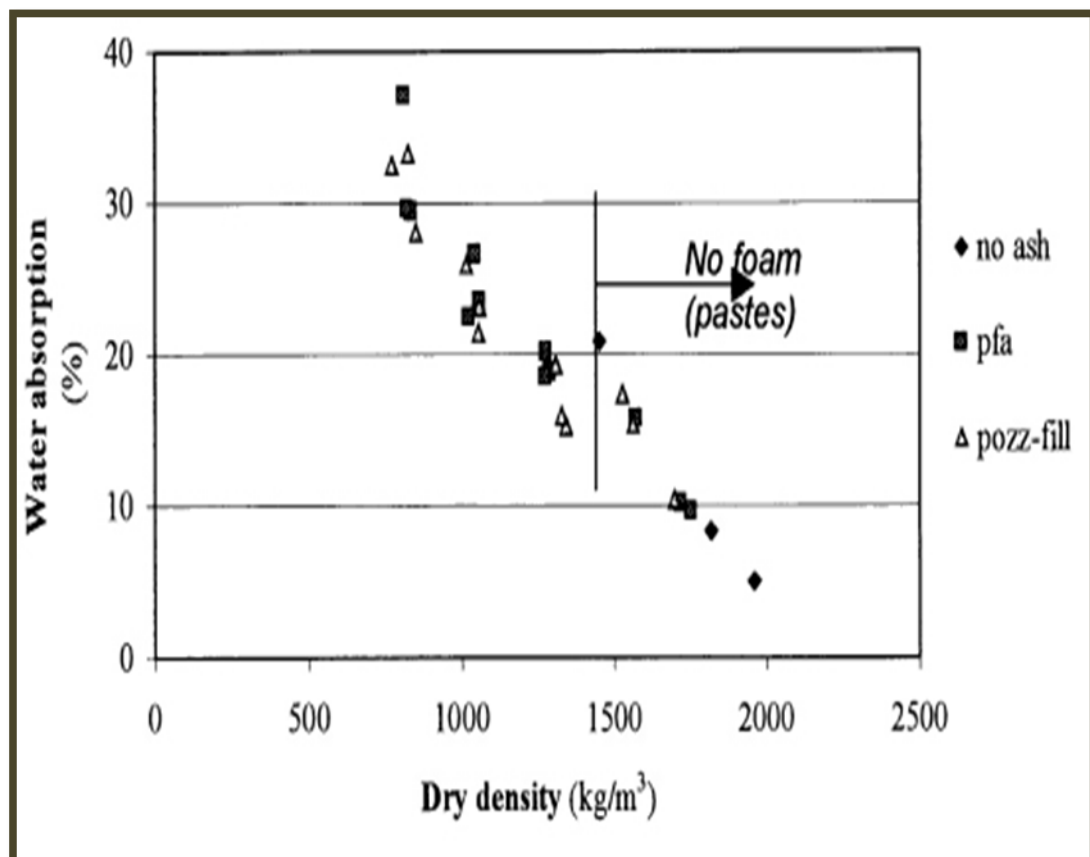


Figure 2.3: Effect of Dry Density on Percentage Water Absorption (Kearsley & Wainwright , 2001)

For the foamed concrete mixtures reported, there are significant differences in density (1000 to 1500 kg/m³) and expressing water absorption as the increase in mass per unit volume as shown in Figure 2.4. 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.

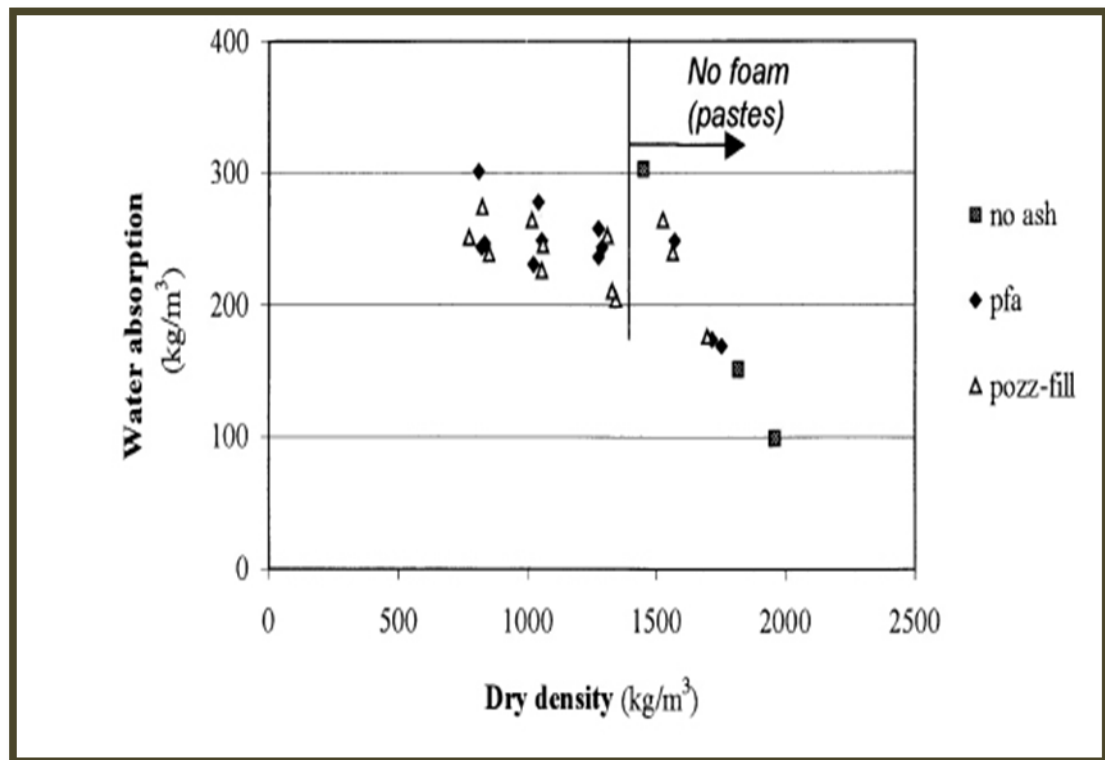


Figure 2.4: Effect of Dry Density on Water Absorption (Kearsley and Wainwright 2001)

According to Kunhanandan Nambiar & Ramamurthy (2006) show that the water absorption of foamed 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 2.5.

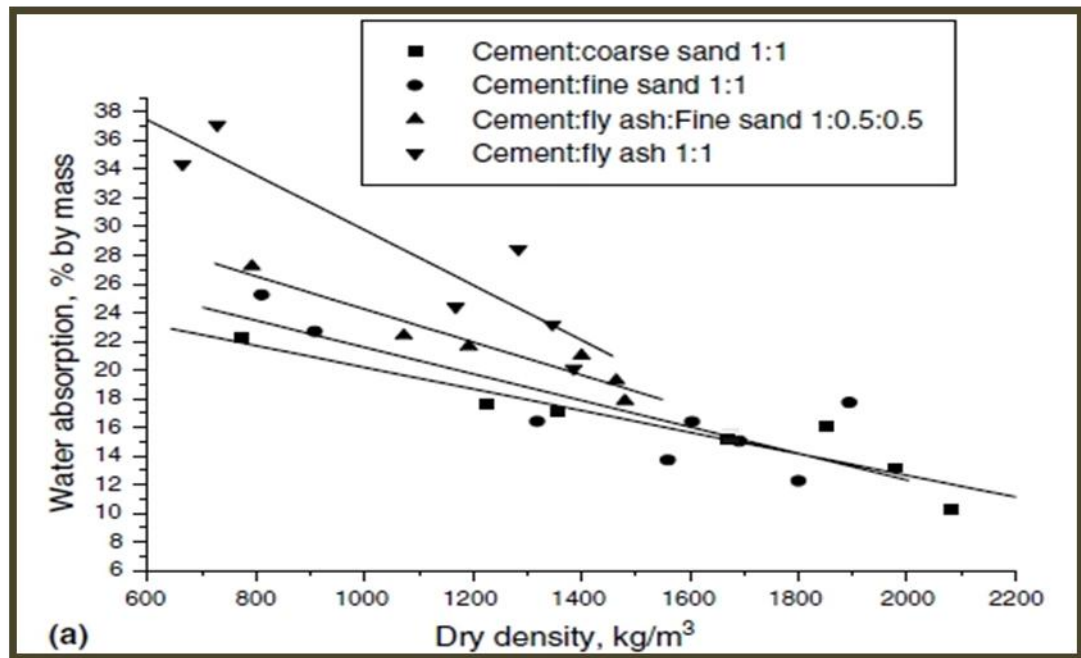


Figure 2.5: Variation of Water Absorption with Different Dry Density and Mixes (Kunhanandan Nambiar and Ramamurthy 2006)

2.3.1.4 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.

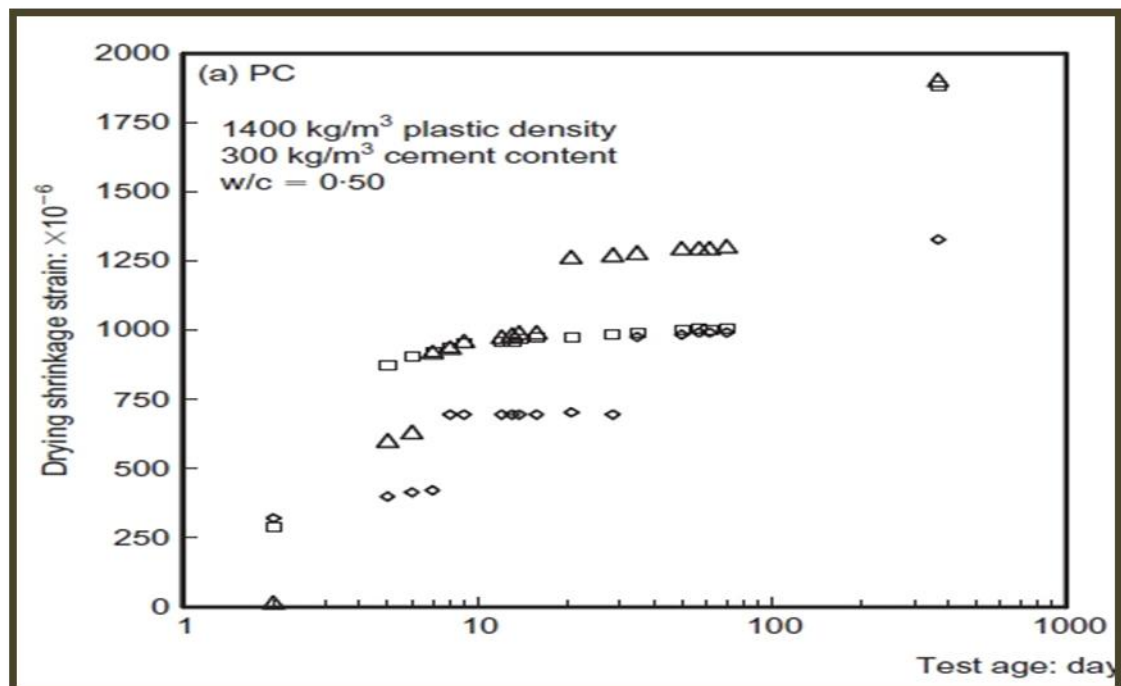
However, for concrete mixtures with a very low W/C ratio, this procedure may last longer if moisture is available. Plastic shrinkage and drying shrinkage are caused by withdrawal of water from concrete under the condition of humidity gradient between the interior of concrete and air. These are the two 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)

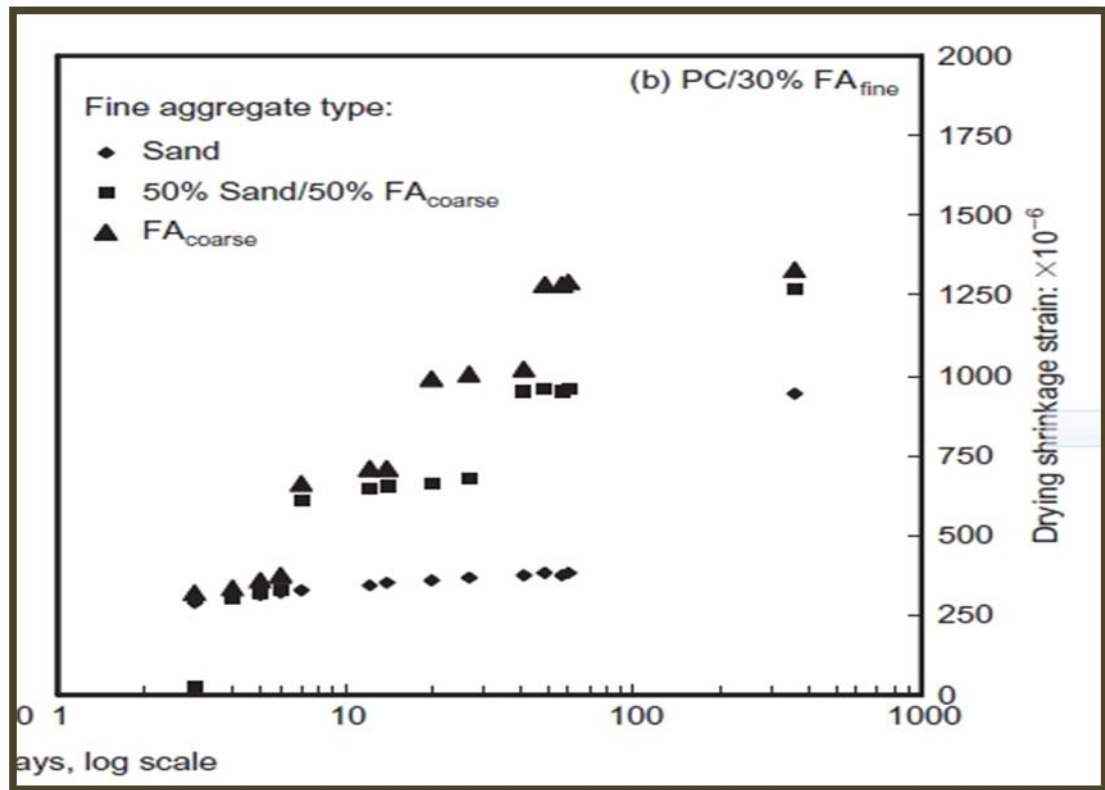
high cement content, its high water content and the lack of coarse aggregate in the mix. The amount of drying shrinkage tends to increase with increasing foamed content (i.e. with decreasing density of the concrete) and with increasing temperature. According to McGovern (2000), shrinkage usually occurs 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 course, 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 course than the sand foamed concretes. Overall, for the 1400 kg/m^3 plastic density concretes examined, drying shrinkage strains between 940×10^{-6} and 1900×10^{-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 2.6.a and b, when 30% FA fine was used with PC, drying shrinkage strains were up to 2.6 times smaller on the 1400 kg/m^3 specimens at a given test age.



(A)



(B)

Figure 2.6 a & b : Influence of FA Coarse and FA Fine on Early Age Drying Shrinkage of Foamed Concrete (Jones and McCarthy, 2005)

2.3.1.5 Carbonation

The carbonation resistance of relatively high strength, foamed concrete is much lower than that of normal weight concrete. As Dhir (1999) founded, over a period of three months or so the depth of carbonation in a PC/sand mixes, having a plastic density of 1400 kg/m^3 , was in excess of 20 mm. The much higher resistance of the denser foamed concrete might be attributed to its denser structure and its higher cement content. Figure 2.7 describes the carbonation depth of different mixture.

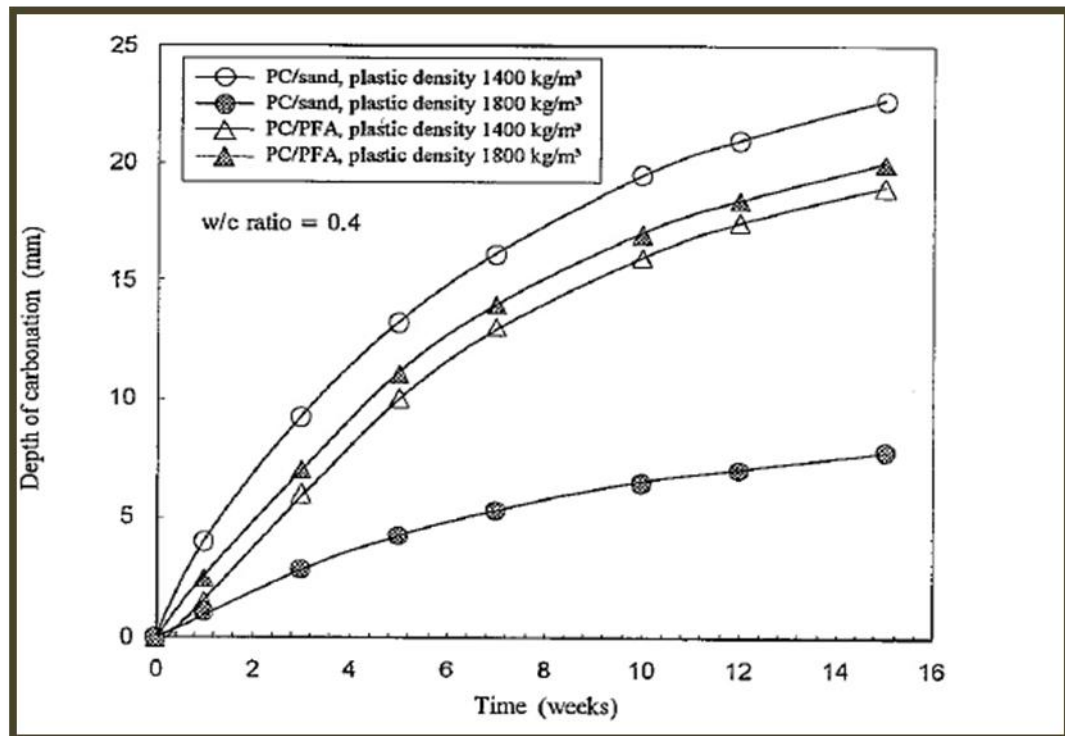


Figure 2.7: Carbonation Resistance of Foamed Concrete (Brady, 2001)

In study conducted by Jones & McCarthy (2005), carbonation resistance was measured for test mixes specimens placed in a 4 - 0.5% CO₂ atmosphere at 55 - 5% relative humidity, the results of which are given in Figure 2.8. All the foamed concrete mixes had high rates of carbonation, with the deepest level of carbonation penetration (23 mm after 15 weeks exposure) noted on 1400 kg/m³ sand concretes. The 1800 kg/m³ FA coarse concretes exhibited greater carbonation depths than the equivalent density, sand fine aggregate concretes; however, at 1400 kg/m³ the ranking order was reversed, although the differences between the two concretes were small.

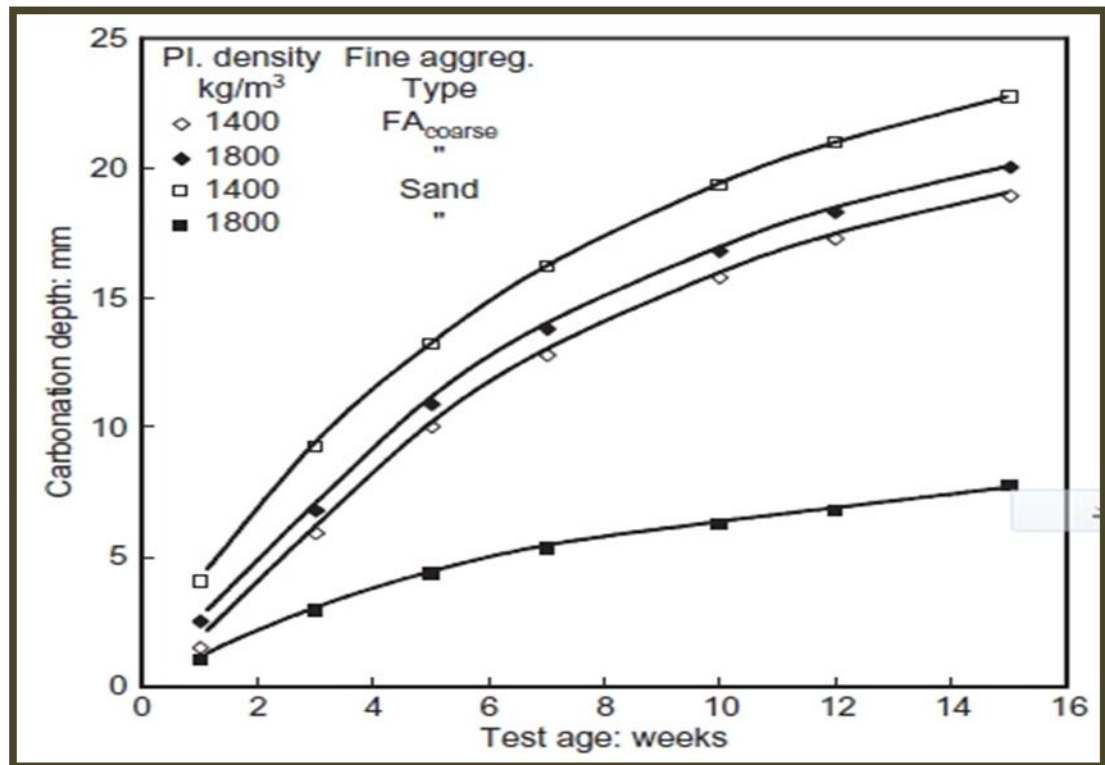


Figure 2.8: Effect of Fines in Carbonation Resistance of Foamed Concrete (Jones and McCarthy, 2005)

2.3.2 Mechanical properties of foamed concrete

2.3.2.1 Compressive strength

The strength of concrete originates from the strength of the hardening cement paste, which is, in turn, originates from hydration products. Compressive strength of foamed concrete influenced by many factor 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 foamed concrete 800, 1250 and 1500 kg/m³. 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. Foamed concrete mixes based on fly ash as filler showed higher strength to density ratios than those based on sand for all density values. Figure 2.9. 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.

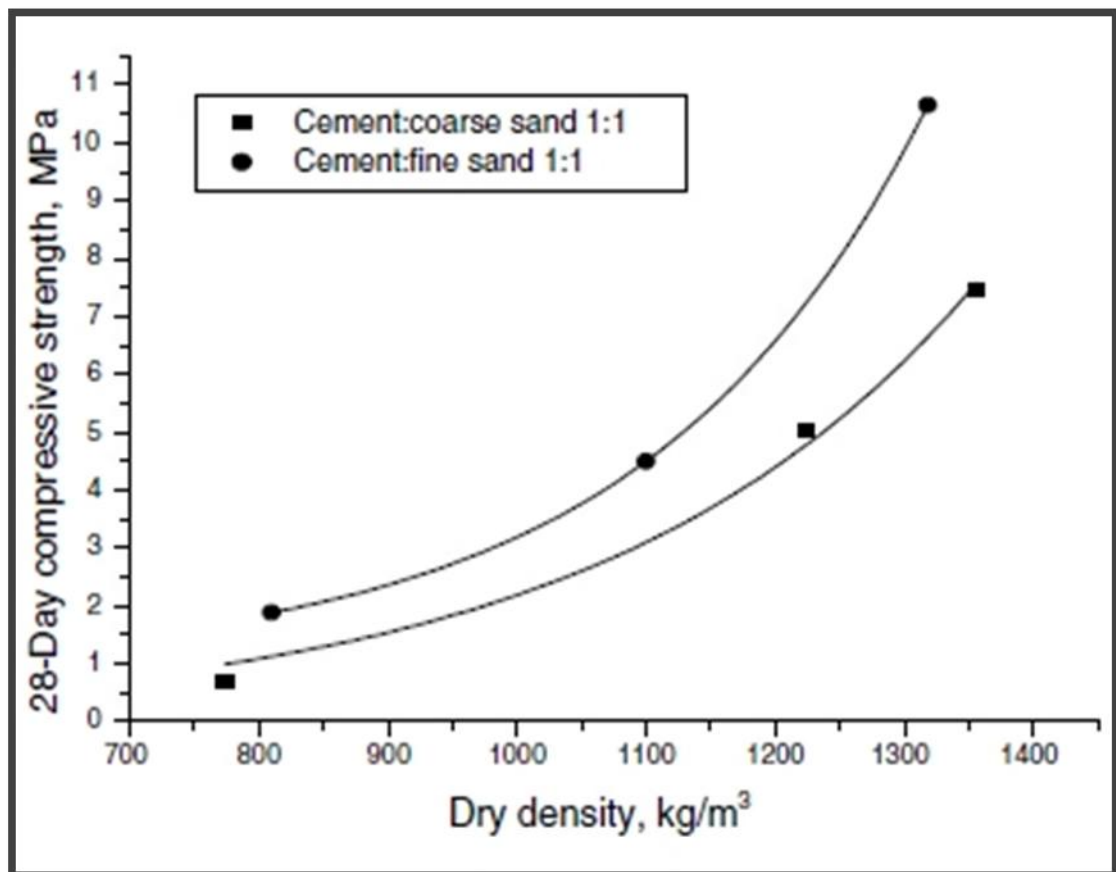


Figure 2.9.a: Strength Density Variation for Mixes with sand of different Fineness (Kunhanandan and Ramamurthy, 2006)

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