

Experimental Production of Sustainable Lightweight Foamed Concrete

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Authors' contributions

This work was carried out in collaboration between all authors. Author AOR designed the study, performed the experimental and statistical analysis, wrote the protocol, and wrote the first draft of the manuscript and managed literature searches. Author MR proof read and type the final draft of the manuscript. All authors read and approved the final manuscript.

Research Article

Received 30th March 2013
Accepted 2nd June 2013
Published 12th July 2013

ABSTRACT

Lightweight foamed concrete is recently acceptable for use in low strength capacity for building and civil construction purposes as a result of its peculiar features such as low thermal conductivity, low self weight and self compacting features hence its high workability. But its major demerit is its difficulty of high strength development when compared with normal concrete. The maximum strength achieved so far is less than 25MPa even at higher density of between 1500kg/m³ and 1800kg/m³. Strength development of foamed concrete depends largely on some factors which are the constituents of the base mix, the density of foam and the water cement ratio of the base mix. This paper studies the base mix parameters to produce a sustainable foamed concrete by substituting cement which is a source of carbon dioxide, a green house emission element, with a cementitious material, fly ash within a range of 10% up to 50% and water cement ratio of 3.0 was used. Notraite PA-1 was used as foam agent and prefoamed method was adopted for the production of the foamed concrete. With a target density of 1600kg/m³, the compressive strength result of 10.5MPa reveals that a high strength sustainable foamed concrete structural panel could only be produced with 10% replacement of cement.

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Keywords: Concrete; sustainable concrete; lightweight foamed concrete; compressive strength; fly ash.

1. INTRODUCTION

The incessant release of anthropogenic greenhouse gases has been causing climate changes over some years now and this fact has been established through research studies that there is global growth of carbon dioxide concentration in the atmosphere. Studies have shown that production of Portland cement alone accounted for approximately 5% of the total global carbon dioxide emissions through various human activities. A further study shows that a tone of concrete produced carbon dioxide of between 0.05 to 0.13 tonnes approximately ninety-five percent of the total estimated carbon dioxide emissions derived from production of concrete [1]. Gore [2], considered buildings as one of the largest end consumer of energy. It was established that building sector accounts for 25 to 40% of final energy demand.

Concrete is considered worldwide as the most important building material and also the most common materials used in the construction of building or civil engineering structures. The reason behind this are not farfetched; if concrete is properly and adequately designed and produced, it possess some valuable, conducive and economic features through its properties chemically, physically and mechanically, hence its popularity in the world, its durability and adaptability is worldwide friendly. As a result of its environmental impact also, it remains one of the most costly materials of construction. Concrete is moldable, affordable highly resistance to fire attack, easy to work with and readily available. It can be worked upon to meet up with any specifications or requirements easily modifiable hence term as engineering materials.

Ordinary concrete has been found to contain about 12% cement and 80% aggregates by mass [3]. Furthermore, Mehta, [1] explained that mining large quantities of raw materials for the production of cement such as limestone and clay and fuel such as coal often results in extensive deforestation or denudation and top soil loss. All these need of vast quantity of natural resources to produce estimated billions of tons of concrete each year resulted in great impact on the immediate environment. Apart from the estimated 7% of the global loading of carbon dioxide (CO₂) into the air annually, cement industry through the production of Portland cement is also considered to be energy intensive. Likewise, quite a large quantity of water is required for the production of concrete, this is considered burdensome considering the availability of good fresh water suitable for concrete production [4]. The continuous use of natural aggregate and the use of cement in the production of concrete conventionally likewise has negative effect on the environment. This effect on the habitat is the extraction of aggregates from pits and quarries results in the destruction of the natural habitats of many organisms and in the disturbance of pre-existing stream flow and water resources [5]. With all these deficiency of the contemporary concrete, there is needs for the production of concrete that will be more environmental friendly hence this laboratory experiment.

Sustainable concrete is a concrete that is more friendly to the environment, that maintain a state or nature as it is without compromising the unborn generation potentials. It's a concrete that possess some if not all the green building index parameters such as energy efficiency, indoor environmental quality, sustainable site planning and management, water efficiency, innovation and materials and resources. At least, four out of these parameters must be met by supposed sustainable concrete. The actual reason for the production of green concrete is that we need to live most lightly on the earth surface as much as possible. Green concrete

targets on increasing the resource use of energy efficiency, water and materials efficiency and at the same time reducing the impact of these various activities on human health well being and the environment.

Lightweight concrete is a material with low mechanical properties compared to normal weight contemporary concrete and it was described by Dhir et al. [6], Mellin [7], as a cementitious material that contains a minimum of 20% by volume of mechanically entrained foam in the mortar slurry in which air pores are entrapped in the matrix by means of a suitable foaming agent. Foamed concrete can be manufactured by adding a foaming agent to a cement based mortar. The foaming agent can be applied and the foam formed through a gentle but thorough mixing or the foaming agent can be aerated before being added to the mixture (i.e. prefoaming). A laboratory test conducted on lightweight foamed concrete's long and short term properties revealed that the material could be used for structural elements [8]. The beneficial features among others include low thermal conductivity, which is lesser than $0.5W/mk$, low self weight hence lightweight which is of the range of between $400kg/m^3$ and $1800kg/m^3$. In term of sustainability features, it's energy efficient in production and use. The water efficiency is high compared to normal weight concrete, it is a new innovation and it does not cause environmental degradation because there is no use of aggregates.

Cementitious material includes among others hydraulic cements and some pozzolans that complement hydraulic cement behavior or in some instances act same way as hydraulic cement.

Fly ash is considered to be one of the most widely used cementitious materials and used in about 50% of ready mixed concrete. Generally, complimentary cementitious material contributes to both fresh and hardened properties of concrete since their basic chemical components are similar. Fly ash as one of the cementitious materials can affect concrete as follows, less water to achieve workability, it may delay the setting time, and strength may be depressed during the early days but later increase because of fly ash reaction rates are initially slower but continue longer. It also reduces heat of hydration of concrete, permeability is reduced and resistance to chloride ion penetration is improved. Fly ash can be class C or Class F depending on their microstructures. Class F fly ash is generally used in concrete mix at the dosage of 15% to 25% by mass of the cementitious material while class C fly ash is generally used at the dosages of 15% to 40% dosage depending on the desired effects on the concrete [9]. In the same vein, fly ash according to Jones and McCarthy, Kearsley and Wainwright, [10-13] has been used in various ranges of 30-70% content of cements weight substitute.

1.1 Benefit of Research

The Universal goals based on agenda 21 established in RIO summit in Brazil is a path to follow in all industries to make the earth surface free of green house gas emission in which Carbon dioxide, a constituent of popular hydraulic cement, Portland cement, is a major causes. Using cementitious materials as a partial substitute of the most used and popular cement is quite challenging to achieve a good and acceptable strength as compared to the concrete produced with the popular cement. This research study shall by no means be a beacon of references for any concrete with high substitute of normal cement hence sustainable concrete. This in turn, shall help the environment at large in the reduction of carbon dioxide.

2. MATERIALS AND METHODS

2.1 Materials

The cement used in this research study was ordinary Portland cement type I conforming to ASTM C150 [14] sourced locally and supplied by Tasek Corporation Berhad, the class F fly ash was supplied by a local supplier, Fosroc Sdn. Bhd. And conformed to ASTM C618 [15]. Fine aggregates was sourced and supplied locally in Penang state of Malaysia. The fine aggregate was of 300microns and of specific gravity of 2.52 [16]. Portable water supplied by Penang state water board was used. No chemical additive was used in this experiment. The foam was produced using a protein based foam agent in ratio of 1:35 dilution in water and a Portal PM-1 foam generator available at HBP Laboratory of Universiti Sains Malaysia, Penang, Malaysia, was used to generate the foam to a density of 80kg/m³. Table 1 and Table 2 show the details of the constituents of the materials used in this experiment.

Table 1. Physical property of cement, sand and fly ash.

Types of materials	Density in kg/m ³	Specific surface area(m ² /kg)	Specific gravity
Portland cement(type1)ASTM C 150.[24]	3.15	300	3.16
Fly ash(powder form)	2.3	500	2.06
Fine sand(natural)	2.1	Fineness modulus: 1.65, water absorption	

Table 2. Chemical composition of cement and fly ash

Oxide in %	Cement	Fly ash.
Silicon oxide,	20.55	59.00
Aluminium oxide	4.78	19.58
Ferrous oxide	3.64	7.23
Calcium oxide	63.94	0.54
Magnesium oxide	1.50	4.64
Sulphur oxide	2.77	0.69
Sodium oxide	0.25	0.48
Potassium oxide	0.77	5.95
Chloride oxide	0.0350	0.0114
Loss on ignition	1.24	0.49
Insoluble residue	1.36	-
Free calcium oxide	1.25	-

2.2 Mix Proportion

The mix proportion guideline of ASTM C796 [17] was followed in the laboratory mixing. It is peculiar to cement slurry that was used and modified to suit the production of the foam concrete used for this study with a targeted 1600kg/m³ density.

The mixing procedure commences with the cleaning of the laboratory mixer and drained the excess water, one third of the calculated mixing water was added, then the fine sand followed by the cement. The materials was allowed to mix for almost 3minutes, then the fly ash and the remaining water was added, this was allowed to blend together till appreciable

slurry was achieved. The density of the base mix was then taken in accordance to BS EN 12350 Part I [18] and the slump was also measured as described by Brady et al and Nambiar and Ramamurthy [19-20]. The preformed foam was then added to the base mix through the nozzle of the foam generator according to the calculated amount at the flow rate per seconds. The density of the foam concrete produced was then checked against the target density, 1600kg/m^3 . This is the process that was observed for all the mix proportion used in this study but with the fly ash as substitute of cement content at 10, 20, 30 and 50% and the slump target of 200mm and water cement ratio of 0.30, so as to achieve the objective of this study.

The mixed foam concrete was then casted into cube moulds of 100mm x 100mm sizes and proper molding was achieved by gently tapping the sides of the molds with a rubber hammer and not with a hard object that can cause agitation to the concrete in the mould, this is in accordance to the recommendation of ASTM C796-97 [21]. The samples were mixed under the ambient temperature of between $27\pm 3^\circ\text{C}$ and $29\pm 3^\circ\text{C}$ for the days of the mixing of the samples.

After each mix, the samples were transferred to the laboratory curing space and covered with black plastic sheets to prevent direct exposure to wind and climatic conditions especially evaporation process. The specimen remained under same condition till 24hours later when the specimens were demoulded and the fresh density of concrete was measured, each sample marked before separated and transferred to the location where they will be cured using three different curing systems, which were water curing, moist curing and air curing. Two samples each for each day of the three types of curing system. This was done so that proper and adequate comparison can be achieved for accurate or near accurate result. So in all, six samples were casted for each day's testing, 7, 14 and 28 days making a total of 18 cube samples per experiment with variable parameter of 10% - 50% fly ash content substitute for cement.

All the samples remained under same curing condition till dates of testing except the water and moisture cured that was removed and placed in an oven for 24hrs before testing. The density was checked before placing in an oven and after placing in an oven. A typical mixing proportion used was highlighted in Table 3.

Table 3. The mix proportion

Sample id	Sand (kg)	Cement (kg)	Water (kg)	Fly ash (kg)	Foam %	Target density	Actual density	Slump mm
C1600-NF	58.44	29.22	13.15	-	22.94	1600	1680	200
C1600-FA10	54.84	24.68	9.60	2.74	25.11	1600	1670	200
C1600-FA20	54.84	21.94	12.16	5.48	25.11	1600	1670	200
C1600-FA30	59.82	20.94	14.27	8.99	24.09	1600	1670	200
C1600-FA50	58.44	14.61	13.85	14.61	22.22	1600	1680	200

2.3 Laboratory Tests Methods

Each test result is represented by three 100mm cube samples and all tested to determine their density and compressive strength at various ages of 7, 14 and 28 days after water, moisture and air curing. After demoulding, samples were placed in their respective curing position till the test dates except that of the water and moisture curing that was removed a

day before test and kept in the oven 24hrs before the test. All specimens were tested at saturated surface dry condition and carried out according to BS 1881 Part 114 [22] and the compressive strength of all the samples were tested immediately after the determination of the density according to ASTM C796-97 [23] for each stage.

3. RESULTS AND DISCUSSION

3.1 Saturated Surface Dry Density

Table 4 shows the result of the saturated dry density for all the samples and the compressive strengths. The result of the saturated density shows that the density of all samples containing fly ash reduced significantly compared to that of control samples without fly ash (C1600-NF). And when compared those that contain fly ash it could be observed that at 28days, the density was increasing relatively to the percentage of the fly ash content except for the samples that contain 50% content of fly ash, the more the fly ash, the higher the saturated density. In all this result shows that the presence of fly ash increases the overall density of the samples and this occurs increasingly over days. This is shown in fig. 1.

The density ratio of the mixed was calculated during the mix and this is done by measured the fresh density and divided it by the design density with water-solids ratio of the mixes. Actually the consistency of the wet mix is very important to get the design density. It is observed that at lower water-solids ratio of the mixes, the density ratio is higher than one. The base mix is considered too stiff for proper mixing resulted in the breaking of the bubbles and resulted in density increase. This finding substantiates the findings in earlier studies by Nambiar and Ramamurthy [24].

Table 4. The density results

Sample Id.	Density(kg/m ³)	Density(kg/m ³)	Density(kg/m ³)
	7days	14days	28days
C1600-NF	1721	1730	1740
C1600-FA10	1688	1704	1712
C1600-FA20	1673	1735	1739
C1600-FA30	1712	1722	1735
C1600-FA50	1616	1643	1659

Note: This represent the mean results of the three curing system used for the study

3.2 Compressive Strength

The mechanism of fly ash in the mix is based on the pozzolanic property of the cementitious material hence the reduction in the foam amount used and the consequence reduction in the pore volume inside the mix and pore uniform distribution. The foam volume likewise influences the behavior of flow ability. Fly ash as cement replacement produces good binder and without merging the pore structures together, this result to uniform distribution and coating on each of the bubbles present [24].

The combination of water and pozzolanic activity of fly ash made fly ash a good binder and the reactions produce good binder with longer period of curing. The longer period is because it takes hydration process of fly ash longer period of time to complete.

As shown in Fig. 1, there is progressive increase of the compressive strength of all the samples as the days increases but when the compressive strength of all samples that contain fly ash are compared to that of control samples without fly ash, it could be observed that the samples without fly ash has higher strength. This can likely be as a result of the homogenous nature of foamed concrete and the density of the fine sand that is higher than that of fly ash.

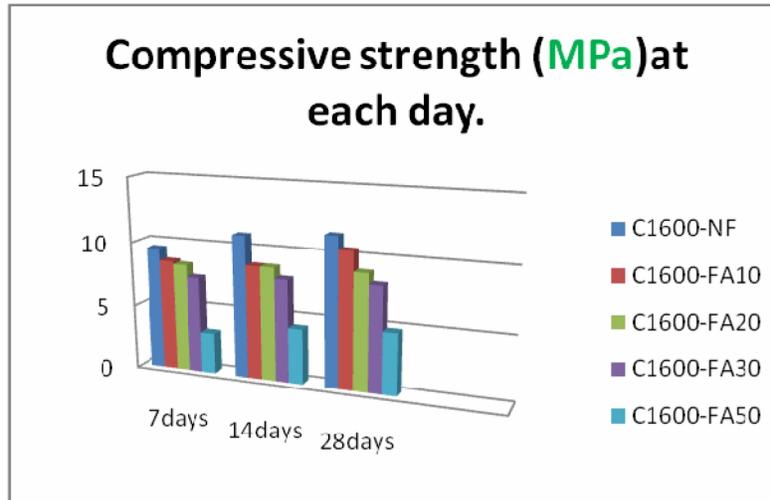


Fig. 1. Shows the compressive strength of samples at test age

Moreso, it was established through studies by Jones and McCarthy [25] that the appropriate days of testing foam concrete with high fly ash content should be minimum of 56days. And also the microstructure feature of fly ash is another factor that can affect the strength of the samples. Meanwhile, the samples without fly ash has the highest compressive strength of 10.5MPa at 28days, this is far lower to the compressive strength of normal concrete of minimum 25MPa at 28days. Among the samples with fly ash content as reflected by Fig 2, the sample with fly ash content of 10%, C1600-FA10 has the highest compressive strength and about 14.3% higher than that of samples that contain 20% fly ash. The samples with 20% fly ash content also has the compressive strength that is higher than that of 30% content of fly ash, while the samples with 50% content has the lowest as reflected in Fig 2. The higher strength of this 10% content of fly ash samples may be as a result of the total amount of the fine aggregates present in the mix as fine aggregates has a higher density than that of fly ash. The higher the volumes of fly ash present, the lower the strength of the samples. Any fly ash replacement level in any mix result to an increase in foam volume and consequently increases the water-solids ratio requirement of the base mix. More so, these tests were taken at early stage during which the pozzollanic nature of fly ash might have not been fully maximized. Scientifically, the fine particles of fly ash get absorbed on the oppositely charged surfaces of cement particles hence disturbed flocculation. This action leads to the dispersion of cement particles adequately and also trap large amount of water. Apart from this, the spherical shape cum smooth fly ash particles surface help to minimize the inter particles friction and thus facilitates mobility. With this, there is water demand reduction in the mix hence reduction in drying shrinkage which may have being as a result of amount and quality of cement and water volume in the mix.

The lower strength at higher substitute volume of fly ash goes to indicate that there is a limited limit to which hydraulic cement can be substituted in foam concrete so that the compressive strength will not be affected. With this indication, then it will be suggested that a certain limit of probably 20% substitute should be adopted for foamed concrete that is to achieve structural strength. It can also be deduced that, a sustainable foamed concrete with a maximum 20% substitute of hydraulic cement can be achieved. This can go a long way to reduce the carbon dioxide content of foamed concrete hence sustainable. As study by Obla [26] shows that every ton of cement produced leads to about 0.9tons of carbon dioxide and a typical cubic yard (0.7643m^3) of concrete contains about 10% by weight of cement. With this expression, a sustainable concrete as produced will by no means reduce some certain percentage of carbon dioxide with substitution of cement by certain percentage of supplementary cementitious material as fly ash.

3.3 Drying Shrinkage

Dry shrinkage is as a result of loss of adsorbed water from the mix materials. The indication of this in foamed concrete and aerated concrete generally is based on its peculiar high porosity and pores specific surface area. The total porosity is between 40%-80% and the specific surface area is around $30\text{m}^2/\text{g}$ as mentioned by Jones and McCathy [10].

The absence of coarse aggregates in foamed concrete base mix made foam concrete to be prone to high drying shrinkage which is up to 10 times greater than those experienced on normal weight concrete as confirmed by a study by Jones et al [13]. The shrinkage of foamed concrete reduces with density. In this study, the shrinkage is found to be lower as a result of the fine aggregates which restrain shrinkage better than when fly ash or other cementitious materials was used as filler rather than when use as cement replacement. For, all the days of test the shrinkage was within the ranges of values as shown in Fig. 2 and this reduces as the samples grow in ages. A study by McGovern [27] established that shrinkage of foamed concrete normally occurs within 20days of casting. The effect of fly ash as cement replacement generally reduces drying shrinkage strain. The result shown in Table 5 reveals that fly ash as cement replacement reduces shrinkage and this may be connected to some adamant particles of fly ash in the course of hydration process, i.e remain non reactive in the process. These non reactive particles cause restraint and influence the pore structure hence low shrinkage value.

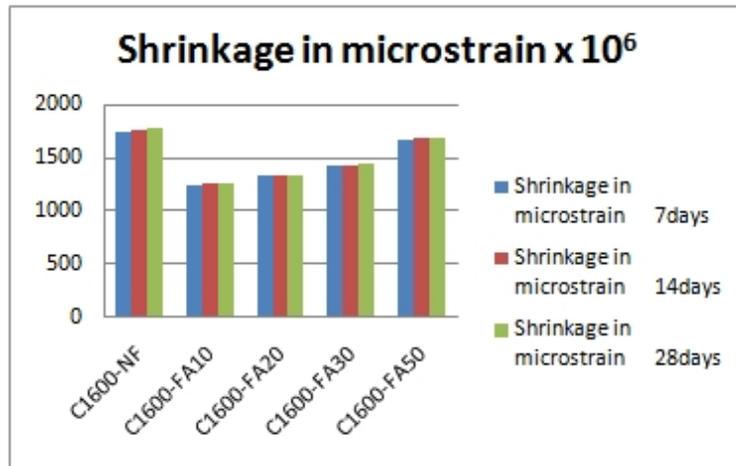


Fig. 2 shows the Shrinkage values of the specimen at different tested ages

3.4 Modulus of Elasticity

The modulus of elasticity of the samples was determined according to BS 1881; Part 121[28] and it was observed to be as a matter of the compressive strength of the foamed concrete. In this study, it was calculated at the age of 7, 14 and 28days and shown in Fig. 3. This is found to be higher and it may be due to the interlocking of fine aggregates used in the base mix. Although, generally it is observed that the modulus of elasticity of foamed concrete is far lower compared to that of normal weight concrete and this is as a result of the absence of coarse aggregates in the mix.

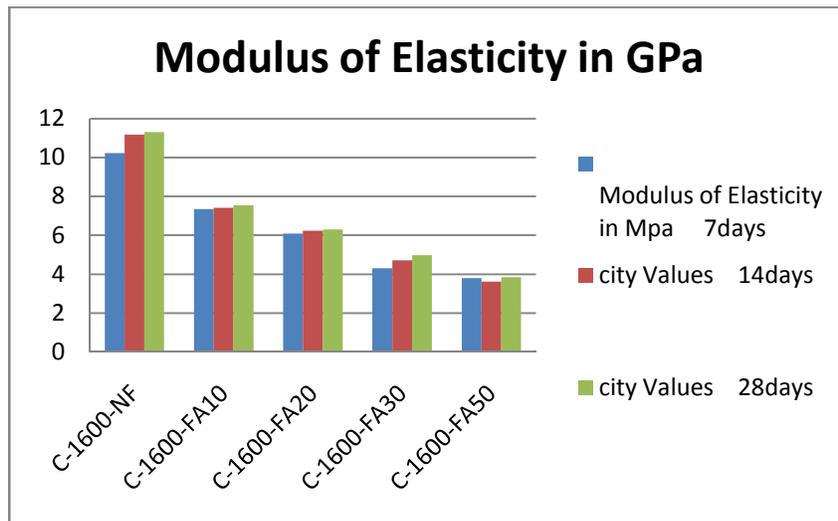


Fig. 3 shows the Modulus of Elasticity values

3.5 Water Absorption

Essentially, water absorption of foams concrete is influenced by the connection of pores and voids. This formation is different with the inclusion of fly ash in the mix. According to a study by Nambiar and Ramamurthy [24], the paste phase is the factor influencing water absorption and not all pores react to water absorption. The paste phase is the result of the hydration process that occurs due to reaction of cement with water and the fly ash in the mix. Pores in some instances also relate to the total volume of foam in a mix. Differences in water absorption is in response to the densities, low densities result in higher water absorption and this is because of large volume of pores. Another factor that influences water absorption is the type of filler and additives. In this experimental study, fly ash as cement replacement gave lower range of water absorption percentage. This may be as a result of uniform distribution of pore structures of fly ash present in the mix. Closed cells structures among particles retard water movement within foamed concrete hence the low level of water absorption. Table 5 shows the result of the water absorption of the specimens over the period of test.

Table 5. Water absorption

Samples	Water absorption in %
C 1600-NF	0.089-0.097
C 1600-FA10	0.087-0.091
C 1600-FA20	0.069-0.085
C 1600-FA30	0.051-0.054
C 1600-FA50	0.030-0.036

4. CONCLUSIONS

The result of this experimental study of sustainable lightweight foamed concrete production with various volume of fly ash as substitute of cement reveals the following.

- The saturated surface dry density results shows that the presence of fly ash reduce the saturated dry density of samples compared to the control samples.
- The Compressive strength was also reducing relatively to the volume of fly ash present in the samples. The higher the fly ash volume, the lower the compressive strength.
- That the production of sustainable concrete is possible with the substitution of the volume of hydraulic cements hence reduce carbon dioxide emission.

COMPETING INTERESTS

All the authors declare that there are no competing interests whatsoever.

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