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Applications of Foamed Lightweight Concrete

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Abstract. Application of foamed concrete is increasing at present due to high demand on foamed concrete structures with good mechanical and physical properties. This paper discusses on the use of basic raw materials, their characteristics, production process, and their application in foamed lightweight concrete with densities between 300 kg/m^3 and 1800 kg/m^3. It also discusses the factors that influence the strengths and weaknesses of foamed concrete based on studies that were conducted previously.

1 Introduction

The introduction of polymers into cementitious materials to improve the bond adhesion, flexibility and workability of resultant composite was first made in the 1930s with natural rubber. However, the main difficulty encountered when using this natural polymer material is the inability to alter the chemical structure and tailor the physical properties to those required for a particular application (Miller 2005).

The primary reason for introducing polymer materials into concrete and cement-based compounds is to improve the physical and mechanical characteristics of the resultant cementitious material to be lightweight, self compacting, high workability, good thermal insulation, and can be cut and nail/screw easily (Koh 2008). One of the important characteristics of lightweight concrete is light or low-density foamed. El-Reedy, 2009 has state the classification of lightweight concrete in Fig. 1.

Foamed concrete is formed when air-voids are entrapped in mortar by suitable foaming agent. It possesses high flow ability, low self-weight, minimal consumption of aggregate, controlled low strength and excellent thermal insulation properties. Foamed concrete with densities between 400 kg/m^3 and 1600 kg/m^3 is obtained for the purpose of structural, partition, insulation, and filling grades (Ramamurthy 2009).

An improvement in the workability and bond adhesion will also increase the flexural and tensile strength. Polymer modified cementitious materials also showed an increase in durability and water resistance. Hence, the addition of the polymer into cementitious system enabled its use in more complex structures and situations (Ohama 1998).

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Fig. 1. Classification of lightweight concrete.

No-fines Concrete	**Lightweight Aggregate Concrete**	**Aerated Concrete**	
		Chemical	**Foaming Mixture**
Gravel	Clinker	Aluminium powder	Performed foam
Crushed stone	Foamed slag	Hydrogen peroxide and bleaching powder	Air-entrained foam
Coarse clinker	Expanded clay		
Sintered pulverized fuel ash	Expanded shale		
Expanded clay or shale	Expanded slate		
Expanded slate	Sintered pulverized fuel ash		
Foamed slag	Exfoliated vermiculite		
	Expanded perlite		
	Pumice		
	Organic aggregate		

The initial use of polymers in concrete systems is achieved using a liquid additive, which was added to the cementitious material during mixing. However, in certain circumstances it has become more advantageous nowadays to include the polymer in the actual cementitious powder, which polymerizes when in contact with water during the mixing process. This allows the quantity of polymer throughout the mix to be controlled more precisely, reducing the errors associated with the mixing of the dispersion directly with the cement-based product. This can have the advantage of lowering the cost of manufacturing and construction process.

2 Materials and method

2.1 Materials

Main materials to produce foam concrete are mortar or cement grout and foam. Mortar is normally fresh concrete which contains a mix of cement, fine sand and water. Additional mix is foam protein-based or synthetic to reduce the weight of the concrete. Hydrolyzed proteins have higher strength performance, while synthetic based foaming agents are easier to handle, cheaper and requires less energy and can be stored longer.

2.2 Production methods

Foaming admixtures is based on BS8443:2005. Barnes 2009 and Ramamurthy 2009 discussed the method of producing foam, known as the wet method and the dry method.

(i) Wet foam has a large loose bubble structure. Although stable, is not recommended for the production of foamed concretes with densities below 1000 kg/m^3. It involves spraying a solution of the agent and water over a fine mesh, leading to a foam with bubbles of size between 2 mm and 5 mm.

(ii) Dry foam is extremely stable. Stability is a characteristic that has become increasingly important as the density of the foamed concrete reduces. It is produced by forcing a solution of foaming agent and water through restrictions whilst forcing compressed air

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into the mixing chamber. The resulting bubble size is smaller than wet foam, i.e. less than 1 mm in diameter.

After the foam is stable, it can be mixed into the concrete using two method (Barnes 2009), i.e. the inline or pre-foam methods.

2.1.1 Inline

Cement, fine sand and water are placed into a unit where they are blended together with the foam. The mixing process is more controlled and greater quantities can be easily produced. There are two types of processes, depending on whether the wet method or dry method is used.

In wet method, the base materials are the same as those used in the pre-foam system, but are generally wetter. The base material and the foam are fed through a series of static inline mixers where the two are mixed together. The foam and the base materials are blended together and continuously monitored by an on-board density monitor. The output volume is not governed by the size of the pre-mix concrete truck, but by the density of the foamed concrete, where one 8 m^3 delivery of base material can produce 35 m^3 of a 500 kg/m^3 foamed concrete.

2.1.2 Pre-foam

In pre-foam method, pre-mix concrete truck delivers the base materials to site and then the pre-formed foam is injected directly into the back of the truck whilst the mixer is rotating. The advantage of this method is that, relatively small quantities can be ordered. However, it does rely on the mixing action of the concrete truck. Densities in the range of 300 kg/m^3 to 1200 kg/m^3 can be achieved. Typically foamed air in this method is in the range of 20% to 60% of air.

3 Properties

Ramamurthy, 2009 listed types of foam concrete properties as:

(i) fresh state properties to be familiar with the consistency and stability,
(ii) physical properties to recognize the drying shrinkage, air-void system and density,
(iii) mechanical properties to identify the compressive strength, flexural and tensile strengths, and modulus of elasticity,
(iv) thermal properties to classify the thermal conductivity, thermal expansion, specific heat, and flammability,
(v) strength prediction models,
(vi) durability of foamed concrete such as permeation characteristics, and resistance to aggressive environment, and
(vii) functional characteristics for instance thermal insulation, acoustical properties, and fire resistance.

Table 1 summarizes the applications of foamed concrete based on its density (Aldridge 2005, Liew 2005, Jones 2005, Barnes 2009). Common density of foamed concrete to be developed is between 1000 kg/m^3 to 1500 kg/m^3, which generally is used for housing applications, prefabrications and cast-in place wall, either load bearing or non-load bearing structures.

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Table 1. Summary of foamed concrete applications based on density

Density (kg/m^3)	Application
300-600	Replacement of existing soil, soil stabilization, raft foundation.
500-600	Currently being used to stabilize a redundant, geotechnical rehabilitation and soil settlement. Road construction.
600-800	Widely used in void filling, as an alternative to granular fill. Some such applications include filling of old sewerage pipes, wells, basement and subways.
800 - 900	Primarily used in production of blocks and other non-load bearing building element such as balcony railing, partitions, parapets, etc.
1100-1400	Used in prefabrication and cast-in place wall, either load bearing or non-load bearing and floor screeds.
1100-1500	Housing applications.
1600-1800	Recommended for slabs and other load bearing building element where higher strength required.

Apart from the density of the aggregates, the density of the concrete also depends on the grading of the aggregates, their moisture content, mix proportions, cement content, water to binder ratio, and chemical and mineral admixtures. Besides characteristics of the materials, it also depends upon the method of mixing, compaction, and curing condition (Osman Unal 2007).

Barnes (2009) reported that there is a correlation between the density and compressive strength of foamed concrete. Comparing the wet density of the foamed concrete at the point of discharge, with the wet density determined during development testing gives an estimate of likely strength at a given age.

The cellular structure of foamed concrete contributes to good thermal insulating properties and low thermal conductivity values. Table 2 shows that the thermal conductivity of foamed concrete ranges between 0.1 W/mK and 0.7 W/mK for dry densities of 600 kg/m^3 to 1600 kg/m^3. These thermal conductivities of foamed concrete are typically 5% to 30% of those measured on normal weight concrete. Thermal conductivities reduces with decreasing densities.

Table 2. Typical properties of foamed concrete based on British Concrete Association (BCA)

Dry Density (kg/m^3)	Compressive strength (N/mm^2)	Thermal Conductivity (W/mK)	Modulus of Elasticity (kN/mm^2)	Drying Shrinkage (%)
400	0.5 – 1.0	0.10	0.8 – 1.0	0.30 – 0.35
600	1.0 – 1.5	0.11	1.0 – 1.5	0.22 – 0.25
800	1.5 – 2.0	0.17 – 0.23	2.0 – 2.5	0.20 – 0.22
1000	2.5 – 3.0	0.23 – 0.30	2.5 – 3.0	0.15 – 0.18
1200	4.5 – 5.5	0.38 – 0.42	3.5 – 4.0	0.09 – 0.11
1400	6.0 – 8.0	0.50 – 0.55	5.0 – 6.0	0.07 – 0.09
1600	7.5 – 10.0	0.62 – 0.66	10.0 – 12.0	0.06 – 0.07

Foamed concrete depends on its many characteristics for its different applications in building construction. These are some guidelines on production and processes to produce the best foamed concrete.

The strength of foamed concrete are increase by :

(i) decreasing porosity (less foam),
(ii) using finer sand, less than 5 mm (Nambiar 2006),
(iii) introducing small air bubbles (between 0.1 mm and 1.5 mm) with uniform distribution (Brady 2001, Kunhanandan Nambiar 2006),

(iv) using fly ash and silica fume for pozolanic reaction,
(v) air curing (compared to sealed/ water curing) (Kearsley 1998,), and
(vi) usage of polypropylene.

4 Conclusions

Applications and properties of foamed lightweight concrete have been discussed in this paper. In extension of this paper, the production of lightweight concrete for insulation purposes with target density below 1500 kg/m^3 will be carried out. The natural material considered is the palm kernel oil-based polyurethane, which will be mixed with concrete for the production of building materials converging on wall provisions.

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