Available online at www.sciencedirect.com
SCIENCE DIRECT®

Cement & Concrete Composites 28 (2006) 475–480

Cement & Concrete Composites

www.elsevier.com/locate/cemconcomp

Influence of filler type on the properties of foam concrete

E.K. Kunhanandan Nambiar, K. Ramamurthy *

Building Technology and Construction Management Division, Department of Civil Engineering, Indian Institute of Technology Madras, Chennai 600 036, India

Received 25 January 2005; accepted 5 December 2005
Available online 24 January 2006

Abstract

Most of the investigations on foam concrete in the past have been confined to neat cement paste, cement paste with partial replacement with admixtures and to cement–sand mixes. This paper reports the results of a systematic study to ascertain the influence of filler type (i.e., sand and fly ash) and the particle size of sand on the properties of moist cured foam concrete. This study shows that the consistency of mixture, for achieving pre-formed foam concrete of design density, mainly depends on the filler type. The flow behaviour of foam concrete is mainly influenced by the foam volume. A reduction in particle size of sand caused an improvement in strength of foam concrete. For a given density, replacement of sand with fly ash resulted in higher strength. Finer filler resulted in a higher ratio of strength to density.

Keywords: Pre-formed foam concrete; Filler type; Density ratio; Flow behaviour; Fly ash

1. Introduction

Pre-formed foam concrete is manufactured by adding foam, prepared by aerating a foaming agent solution, to cement paste or cement mortar. The composition, physical properties and uses of foam concrete were discussed in detail by Valore [1,2], Short and Kinniburgh [3], Rudnai [4] and Taylor [5]. Although several investigations have been conducted on the properties of foam concrete, most of them deal with cement–sand mixes, neat cement paste with or without partial replacement using admixtures [6–11]. Few studies report on the influence of filler type on the properties of foam concrete. By using fly ash as filler (fine aggregate) instead of sand, the high volume utilization of fly ash becomes possible, thus providing a means of economic and safe disposal of this waste product. Comparison of strength of air-cured foam concrete made with cement–sand and cement–fly ash for masonry by Durack and Weiqing [12] show that for products of comparable density, mixes with fly ash as fine aggregate in place of sand gave relatively higher strength. This paper discusses a systematic study on the influence of filler type and fineness of sand on the properties of foam concrete made using pre-formed foam.

2. Experimental programme

2.1. Parameters investigated and mix compositions

As the experimental programme was aimed at studying the effect of the fillers on the properties like density, flow behaviour, water absorption and strength of foam concrete, 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 viz. 1000, 1250, 1500 kg/m^3 were arrived at as per ASTM C 796-97 [13]. 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.

* Corresponding author. Tel.: +91 44 2257 8309; fax: +91 44 2257 8281.
E-mail address: vivek@iitm.ac.in (K. Ramamurthy).

0958-9465/$ - see front matter
doi:10.1016/j.cemconcomp.2005.12.001

Table 1
Physical and chemical properties of cement and fly ash used

Properties Physical		Cement		Fly ash
Blaine fineness (m^2/kg)		391		252
Specific gravity		3.13		2.09
28-day compressive strength (MPa)		54.7		–
Chemical	% By mass	IS 12269-1987 [14]	% By mass	ASTM C 618 (Class F) [15]
SiO_2	19.3	–	63.6	–
CaO	61	–	1.57	<10
Al_2O_3	5.687	–	28.19	–
Fe_2O_3	6.036	–	2.99	–
MgO	1.875	6	0.54	5 (max)
MnO	–	–	0.03	–
Na_2O	–	–	0.05	–
K_2O	–		0.003	–
SO_3	1.67	2.5	0.26	–
Loss on ignition	0.2963	4	0.85	–
Soluble residue	1.489	2	–	–
Al_2O_3/ Fe_2O_3	0.94	0.66	–	–
$SiO_2 + Al_2O_3 + Fe_2O_3$	–	–	94.78	70 (min)

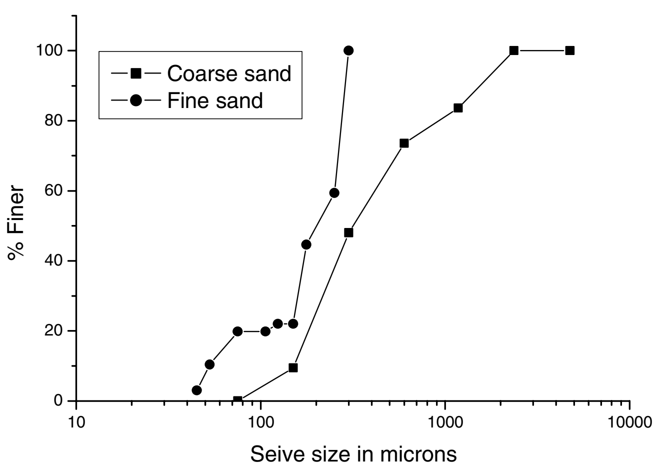

Fig. 1. Grain size distribution of sands used.

2.2. Materials

A locally available foaming agent was diluted with potable water in a ratio of 1:3 by weight, where after foam was produced by aerating to a density of 50 kg/m^3. Fifty three grade Ordinary Portland Cement [14], coarse river sand (specific gravity = 2.66), pulverized river sand finer than 300 μm (specific gravity = 2.52) and class F fly ash conforming to ASTM C 618 [15] were used. The properties of cement and fly ash used in this study are presented in Table 1 and the grain size distribution of two types of sand used is shown in Fig. 1.

2.3. Details of study

The consistency of the mix before adding foam and the flow characteristics of the mix after adding foam were determined by measuring the flow % using a standard flow cone [16]. After filling the cone with the mixture, the cone is lifted and average flow of concrete is measured without raising and dropping of the flow table as it may affect the foam bubbles entrained in the mix. The fresh density of foam concrete was measured by filling a standard container of known volume. The specimens were removed from the mould after 24 h and were subjected to moist curing for 28 days. The compressive strength, dry density and water absorption were determined. Even for mixes with fly ash, the 28-day strength test was conducted so that comparison with the cement–sand mixes would be possible. Six 50 mm cube specimens, as per the recommendations in ASTM standards [17], were cast for the study of each parameter.

3. Results and discussion

3.1. Effect of water–solids ratio on design density

As the foam is added to the wet foam concrete mix, the consistency of the wet mix is very important to get the design density. Fig. 2(a) and (b) show the variation of density ratio (measured fresh density divided by design density) with water–solids ratio for mixes with different filler type for each of the design densities, viz., 1000 and 1500 kg/m^3, respectively. It is observed that at lower water–solids ratios, i.e., at lower consistency, the density ratio is higher than unity. The mix is too stiff to mix properly thus causing the bubbles to break during mixing resulting in increased density. At higher water–solids ratios there is also an increase in density ratio as higher water contents make the slurry too thin to hold the bubbles resulting in segregation of the foam from the mix along with segregation of the mix itself thus causing an increase in measured

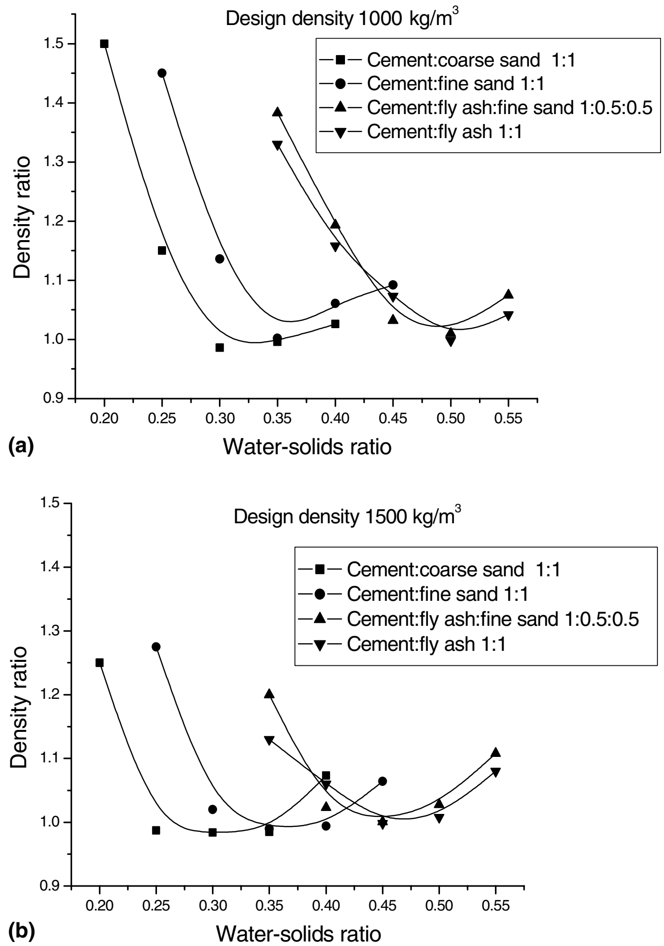

Fig. 2. Variation of density ratio with water–solids ratio for different filler type.

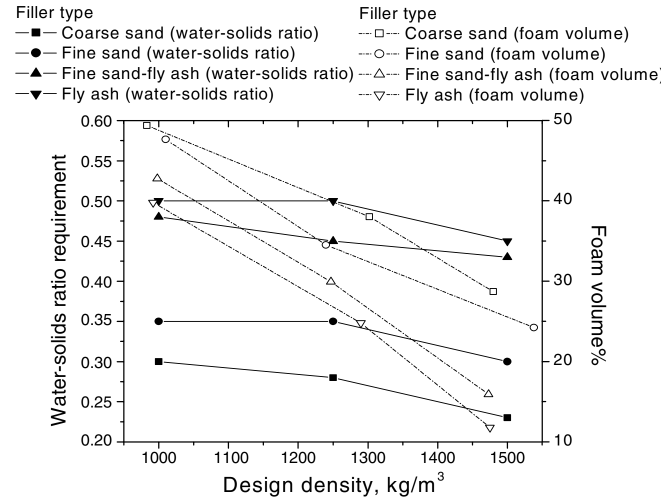

Fig. 3. Consistency requirement in terms of water–solids ratio for different densities.

density. Therefore, as shown in Fig. 2(a) and (b), a density ratio of unity or nearly unity is achieved only at a particular consistency. This consistency requirement for the mix before adding foam to it can be expressed in terms of water–solids ratio. It is also observed that the water–solids ratio required to obtain a density ratio value of one, depends on the filler type.

Water–solid ratios required to achieve a density ratio of unity for various densities and corresponding foam volume requirements are presented in Fig. 3. Due to higher surface area, foam concrete mixes with fly ash require relatively higher water–solid ratios compared to mixes with sand. At the same time mixes with fly ash require less foam volume due its low specific gravity (2.09) compared to fine sand (2.52). The water–solids ratio requirement reduces only marginally with an increase in density, but the foam requirement reduces steeply. The above observations show that the consistency requirement is mainly affected by the filler type and foam volume to be added in the mix has only a marginal influence. All mixes for further investigation on the properties of foam concrete were made at the water–solids ratios corresponding to the filler types and target densities.

3.2. Flow behaviour

In order to study the relative flow behaviour, the flow of mixes before and after the addition of foam is compared in Fig. 4. For a given mix, it is interesting to note that (i) the flow reduce when the foam is added to the mix, and (ii) the flow reduces steeply with a reduction in design density (i.e., increase in foam volume), even though the variation of flow for corresponding mixes without foam is marginal. The reduction in flow after the addition of foam is a maximum at lower densities of the mix. A possible reason for this is that, at lower densities there will be more foam in comparison to paste and the adhesion between the bubbles and solid particles in the mixture increase the stiffness of the paste. The existence of this adhesive force is indicated qualitatively by the observation of flotation of cement and filler in the mixture. For a given density, the flow value is

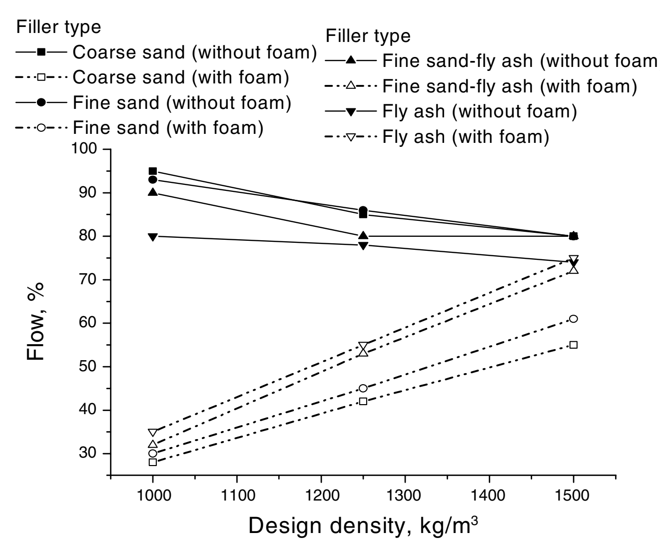

Fig. 4. Variation of flow % with and without foam.

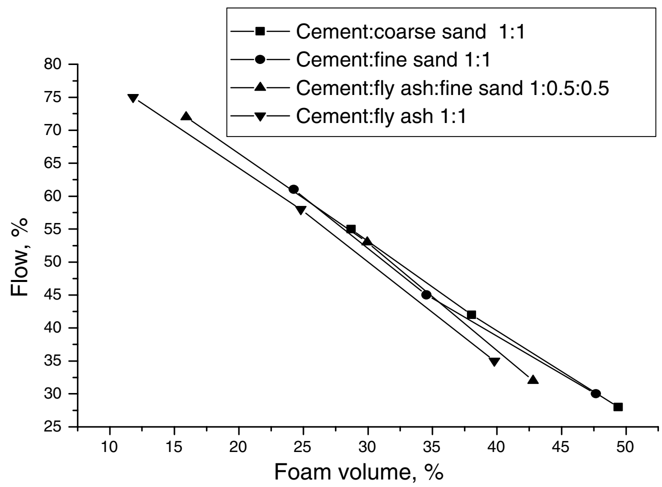

Fig. 5. Variation of flow of foam concrete with foam content.

relatively higher for fly ash mixes as it contains a smaller volume of foam due to its low specific gravity compared to sand. For a given foam volume, the flow of foam concrete is not much affected by filler type (Fig. 5).

3.3. Compressive strength

The effect of fineness of sand on the compressive strength of foam concrete is presented in Fig. 6. 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. Similar results have been reported in literature [5,6]. Cut sections of the specimens viewed through an optical microscope with magnification factor of 20 showed that there was a comparatively uniform distribution of pore in the case of foam concrete with fine sand, while the pores were larger and irregular for mixes with coarse sand. 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. Kearsley and Visagie [18] reported similar observations on the effect of pore size on the strength of foam concrete.

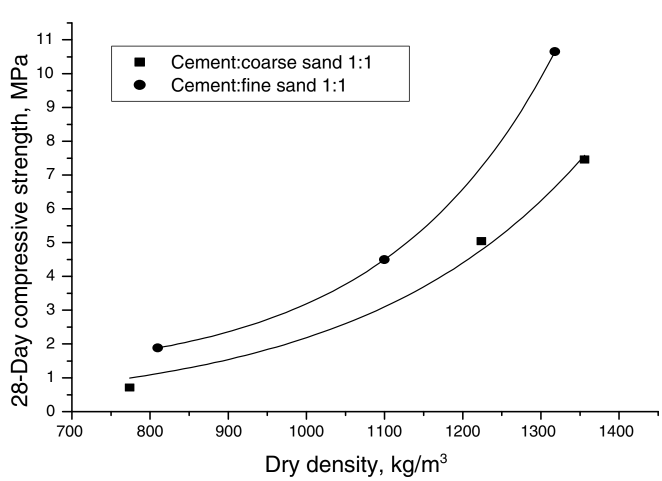

Fig. 6. Strength density variation for mixes with sand of different fineness.

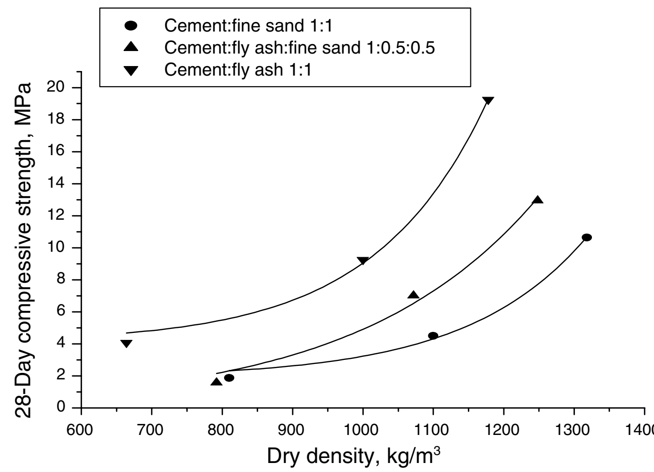

Fig. 7. Strength density variation for mixes with different filler type.

Table 2
Comparison of strength to density ratio (in MPa per kg/m^3 × 1000)

Design density, kg/m^3	Strength to density ratios for foam concrete mixes with			
	Coarse sand	Fine sand	Fine sand–fly ash	Fly ash
1000	0.77	1.73	1.68	2.79
1250	3.87	3.63	5.32	7.11
1500	5.04	6.94	8.64	12.66

In order to study the effect of replacement of sand with fly ash, the relationship between dry density and compressive strength for foam concrete mixes with fine sand, fly ash, and fine sand–fly ash as filler is shown in Fig. 7. For a given density, an increase in fly ash content results in higher strength. Apart from pozzolanicity of fly ash, the lower requirement of foam volume for a given density of foam concrete will also contribute to strength enhancement by reducing the pore volume and facilitating uniform distribution of pores. Durack and Weiqing [12] observed a similar enhancement in strength due to fly ash and this was attributed to the development of strong inter particle bond between the gel matrix and the fly ash particles.

Based on a comparison of strength to density ratio for different mixes in Table 2 the following conclusions can be drawn: (i) for a given mix, the strength to density ratio increases with an increase in design density, and (ii) out of the four types of mixes investigated, foam concrete with fly ash as filler has a higher strength to density ratio for all design density values, i.e., finer filler results in higher strength to density ratio.

3.4. Water absorption

Water absorption was measured on foam concrete cubes after 28-day moist curing as per ASTM C 642-97 [19]. The water absorption at different dry densities of foam concrete

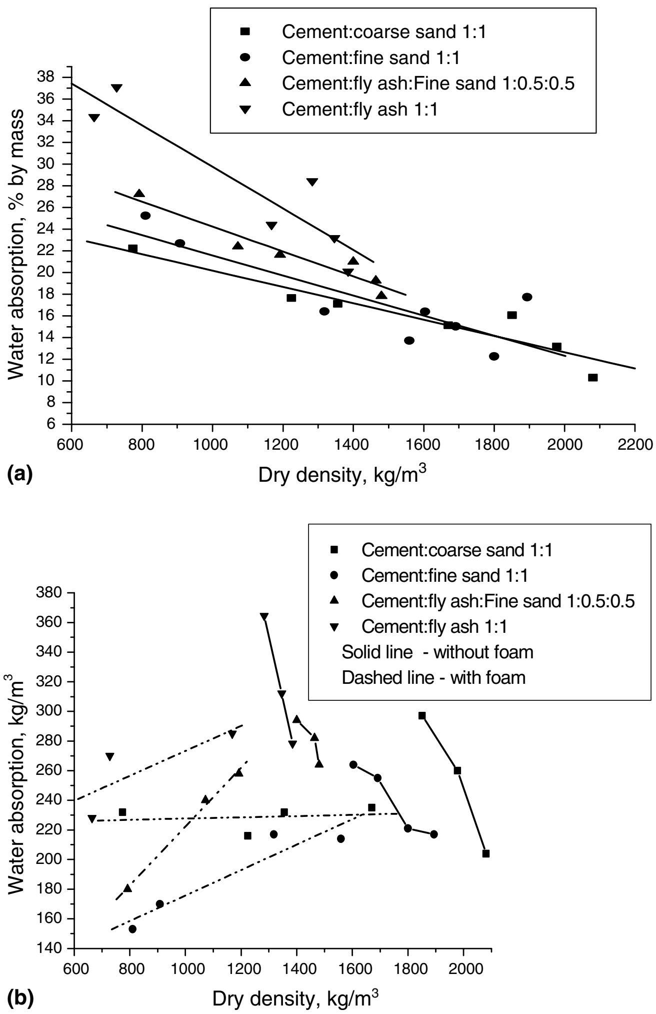

Fig. 8. Variation of water absorption with dry density.

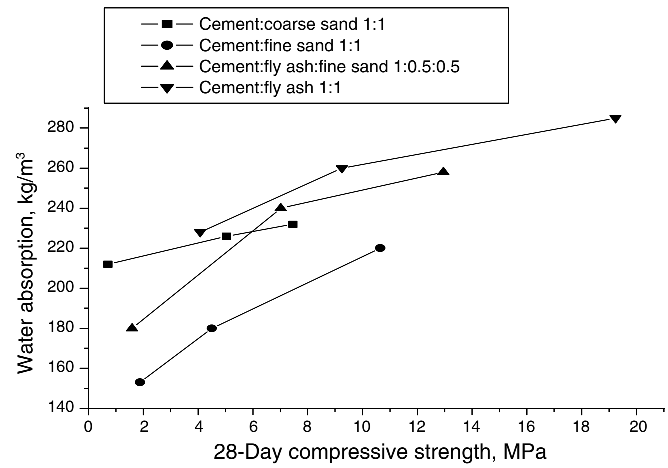

Fig. 9. Variation of water absorption with compressive strength.

is presented in Fig. 8(a) and (b). For a comparison, water absorption of corresponding mixes without foam is also plotted in the same graph. The water absorption of foam concrete, represented as a percentage by mass, increases with a reduction in density (Fig. 8(a)). When the water absorption is represented in kg/m^3 of foam concrete, it is seen that the water absorption is lower at lower densities (Fig. 8(b)). Thus for foam concrete mixtures discussed here, as there is significant differences in density, expressing water absorption as % of dry mass leads to misleading results and it is thus better to express water absorption in kg/m^3. In mixes without foam, where density variation is normally less, the results are not affected by the way in which it is expressed. It can also be seen from Fig. 8(b) that some mixes without foam showed higher water absorption than foam concrete mixes. Thus, mixes with and without foam clearly show that the water absorption is mainly influenced by paste phase and not all artificial pores are taking part in water absorption. This indicates that all of the pores are not inter-connected. The effect of paste phase on water absorption depends on the capillary pores (classified as microcapillaries and macrocapillaries [20]) present in it. The decreasing trend of water absorption thus observed at lower density is attributed to the relatively lower paste volume phase, i.e., smaller capillary pore volume with decreasing bulk density. It can be noted that replacement of sand with fly ash increases the water absorption. Apart from the increased paste content due to the lower foam volume requirement, the higher water–solids (consistency) requirement for fly ash mixture to achieve design density compared to sand mixture (Fig. 3) will also contribute to an increased capillary pore volume and thus in increased water absorption.

Fig. 9 shows the variation of compressive strength with water absorption of foam concrete. It is noted that, unlike conventional concrete, water absorption increases with compressive strength. A possible explanation can be that for a given foam concrete mix, increased density corresponds to an increase in paste volume (capillary pore volume) and reduction in foam volume (artificial pore volume). It can be seen from Figs. 6–8 that compressive strength and water absorption increase with density of foam concrete. Thus, for a given foam concrete mix, water absorption mainly depends on capillary pore volume and the volume of artificial pores governs the compressive strength and density. Prim and Wittmann [21] reported similar conclusions on strength-artificial pore dependency for aerated concrete.

4. Conclusions

The conclusions drawn from this study and summarised below are applicable to the characteristics of the materials used and the range of parameters investigated: (i) the consistency of pre-formed foam concrete mixtures (defined as the water–solids ratio for achieving the target density) mainly depends on the filler type, i.e., relatively higher for mixes with fly ash as filler compared to mixes with sand; (ii) the flow behaviour mainly depends on the foam volume and as the foam volume increases the flow decreases. For a given density, foam concrete with fly ash as filler showed relatively higher flow values; (iii) an increase in fineness of sand causes an increase in strength of foamed concrete; (iv) for a given density, an increase in fly ash content of the mix results in increased strength; (v) finer filler results in higher strength to density ratio, i.e., foam concrete mixes based on fly ash as filler showed higher strength to density ratios than those based on sand for all density values; (vi) the water absorption of foam concrete, because of its reduced density, should rather be expressed in kg/m^3 than as a percentage by weight; (vii) the water absorption of foam concrete is observed to decrease with density. In comparison to cement–sand mixes, cement–fly ash mixes showed relatively higher water absorption.

References

[1] Valore RC. Cellular concretes—Part I. Composition and methods of preparation. J Am Concr Inst 1954;25(9):773–95.

[2] Valore RC. Cellular concretes—Part II. Physical properties. J Am Concr Inst 1954;25(10):817–36.

[3] Short A, Kinniburgh W. Lightweight concretes. London: Applied Sciences Publishers; 1978.

[4] Rudnai G. Lightweight concretes. Budapest: Akademiai Kiado; 1963.

[5] Taylor WH. Concrete technology and practice. London: Angus and Robertson; 1969.

[6] Mc Cormick FC. Rational proportioning of preformed foam cellular concrete. ACI Mater J 1967:104–9.

[7] Tam CT, Lim TY, Lee SL. Relation between strength and volumetric composition of moist-cured cellular concrete. Mag Concr Res 1987; 39(138):12–8.

[8] Kearsley EP, Wainwright PJ. The effect of high fly ash content on the compressive strength of foamed concrete. Cem Concr Res 2001;31: 105–12.

[9] Kearsley EP, Wainwright PJ. Porosity and permeability of foamed concrete. Cem Concr Res 2001;31:805–12.

[10] Kearsley EP, Wainwright PJ. Ash content for optimum strength of foamed concrete. Cem Concr Res 2002;32:241–6.

[11] Kearsley EP, Wainwright PJ. The effect of porosity on the strength of foamed concrete. Cem Concr Res 2002;32:233–9.

[12] Durack JM, Weiqing L. The properties of foamed air cured fly ash based concrete for masonry production. In: Page A, Dhanasekar M, Lawrence S, editors. Proceedings of 5th Australasian Masonry Conference, Gladstone, Queensland, Australia, 1998. p. 129–38.

[13] ASTM. Standard test method for foaming agents for use in producing cellular concrete using preformed foam, ASTM C 796-97, Philadelphia, 1997.

[14] BIS. Specifications for 53 grade ordinary portland cement, I S 12269-1987, New Delhi, 1987.

[15] ASTM. Standard specification for fly ash and raw or calcined natural pozzolana for use as a mineral admixture in portland cement concrete, ASTM C 618-89, Philadelphia, 1989.

[16] ASTM. Specification for flow table for use in tests of hydraulic cement, ASTM C 230-98, Philadelphia, 1998.

[17] ASTM. Standard recommended practice for choice of sample size to estimate the average quality of a lot or process, ASTM E 122-72, Philadelphia, 1972.

[18] Kearsley EP, Visagie M. Micro properties of foamed concrete. Proceedings of congress on creating with concrete (conference on specialist technology and materials for concrete construction), Dundee. UK, London: Thomas Telford; 1999. p. 173–84.

[19] ASTM. Standard test methods for density, absorption and voids in hardened concrete, ASTM C 642-97, Philadelphia, 1997.

[20] Tada S, Nakano S. Microstructural approach to properties of moist cellular concrete. In: Wittmann FH, editor. Proceedings autoclaved aerated concrete moisture and properties. Amsterdam: Elsevier Scientific Publishing Company; 1983. p. 71–88.

[21] Prim P, Wittmann FH. Structure and water absorption of aerated concrete. In: Wittmann FH, editor. Proceedings autoclaved aerated concrete moisture and properties. Amsterdam: Elsevier Scientific Publishing Company; 1983. p. 55–69.