International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 20 (2018) pp. 14806-14812

Characteristics of Foam Concrete Produced from Detergent used as Foaming Agent

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Abstract

Foam concrete is a popular material used for thermal insulation of built infrastructure. In many parts of the world, however, its use is limited owing to higher cost of the foaming agents, an essential ingredient for the production of foam concrete. In this study, the possibility of production of low-cost foam concrete using locally manufactured detergent powder was experimentally investigated. Various foam concrete mixtures using an indigenous detergent as foaming agent were produced and tested for as-placed density, oven-dry density, compressive strength, thermal conductivity, and water absorption and their properties were compared with corresponding mixes produced with regular foaming agent. Besides a comparison of the mechanical characteristics, cost comparison of the two types of foam concretes was made in local currency. Test results showed that production of foam concrete using locally manufactured detergent powder as foaming agent is a viable practice of producing low-cost foam concrete. Resulting foam concrete was found to have mechanical properties comparable to that of foam concrete produced with regular foaming agent. A significant reduction in production cost was estimated when regular foaming agent is replaced with the indigenous detergent powder for the production of foam concrete.

Keywords: Foam concrete; Detergent; Foaming agent; Oven dry density; Compressive strength; Water absorption

INTRODUCTION

Foam concrete is a low-density hardened Portland cement paste or mortar containing large amount of intentionally introduced small air bubbles, called entrained air. Entrainment of air for production of foam concrete can be achieved by mixing a suitable foaming agent (FA) with water in a special mixer. This process produces foam, to which cement-sand slurry is fed to produce foam concrete [1-3]. Past researchers have reported variety of findings concerning the characteristics of foam concrete. Kuhanandan and Ramamurthy [4] reported that the rheological properties of the foam concrete mainly depend on the volume of the foam in the mix. They further found that with reduction in particle size of fine aggregate, the strength of foam concrete was found to increase. In another study [5] these authors found that volume fraction, size, and air void distribution parameters considerably influence the strength and density of foam concrete. In their study on foam concrete Kearsley and Wainwright [6] studied the effect of high content of fly ash on the compressive strength of foam concrete. These authors developed equations to predict the compressive strength of foam concrete up to 1 year of concrete age. In an another study [7] same authors concluded that the compressive strength of foam concrete depends on its porosity and age, a finding on which they based their model upon. Other authors [8-9] have provided account of the insulation characteristics and the possibility of using foam concrete as structural concrete owing to its lightweight and consequent savings in dead load on structural members. Some authors [8-10] have investigated the possibility of using secondary cementitious materials as binder while partially replacing cement with these materials in foam concrete. Fire resistance of foam concrete has been reported to be as good as that of normal concrete or even better than it in certain cases [11]. On the other hand the acoustic insulation characteristics of foam concrete have been reported to be not of any significance [12]. Although foam concrete has been a material of choice for thermal insulation of built infrastructure, the higher cost of FA, which is its essential ingredient, has limited its use, especially in the developing world. This problem can be overcome by using a low-cost detergent as a replacement of FA. Locally produced detergent is aimed to work as air-entraining agent in the mix. This study presents the results of experimental work aimed to investigate the suitability of detergent as air-entraining agent as replacement of FA to produce foam concrete.

MATERIALS AND METHODS

In this work, eight control mixes were produced by using regular foaming agent, and eight corresponding mixes were produced by incorporating locally manufactured detergent (cloth washing surf) as foaming agent were prepared. Variation in the amount of cement, fine aggregate and dosage of FA/detergent was made while water cement ratio and type of detergent/FA were kept constant in these mixes. The experimental matrix is shown in Table 1. Each mix was tested for as-placed density, oven dry density, compressive strength, water absorption, and thermal conductivity according to the relevant ASTM standards [10-11 and 13-24].

Table 1: Control, Detergent and Non air-entrained Mix Designs

	Mix Designation	Cement (per cent)	Sand (per cent)	Sand /Cement ratio	FA (per cent of OPC)
Control Mixes (FA)	0.3FA70C30S	70	30	0.43	0.3
	0.3FA65C35S	65	35	0.54	0.3
	0.3FA60C40S	60	40	0.67	0.3
	0.3FA55C45S	55	45	0.82	0.3
	0.5FA70C30S	70	30	0.43	0.5
	0.5FA65C35S	65	35	0.54	0.5
	0.5FA60C40S	60	40	0.67	0.5
	0.5FA55C45S	55	45	0.82	0.5
Detergent Mixes (D)	0.3D70C30S	70	30	0.43	0.3
	0.3D65C35S	65	35	0.54	0.3
	0.3D60C40S	60	40	0.67	0.3
	0.3D55C45S	55	45	0.82	0.3
	0.5D70C30S	70	30	0.43	0.5
	0.5D65C35S	65	35	0.54	0.5
	0.5D60C40S	60	40	0.67	0.5
	0.5D55C35S	55	45	0.82	0.5

Materials and specimens

Ordinary Portland cement confirming to requirements of ASTM C 150 [15] was used as binder. Table 2 provides the chemical composition of cement. Locally available sand having fineness modulus of 2.45 was used as fine aggregate in all of the mixes. Table 3 shows the results of the sieve analysis and other physical properties of fine aggregate performed in accordance with the provisions of relevant ASTM standards. The FA used in the control mixes carried the commercial name of Feb Foam. For mixes other than control concrete locally produced detergent, leopard surf, was used as air entraining agent. Figure 1 shows the scanning electron microscope (SCM) image of the detergent while figure 2 shows the EDS plot of this detergent. In all mixes the dosage of FA and detergent were kept as 0.3 and 0.5 percent by weight of cement. For all compressive strength tests, 2 in. cubes were used and cured in water until testing age. While 4 in. diameter disc specimens were used for the thermal conductivity tests.

Table 2: Chemical composition of ordinary Portland cement

Oxides	% age
Silicon Dioxide (SiO_2)	19
Aluminum Oxide (Al_2O_3)	9.87
Ferric Oxide (Fe_2O_3)	3.46
Calcium Oxide (CaO)	60
Magnesium Oxide (MgO)	1.63
Sulfur Trioxide (SO_3)	2.63
Sodium Oxide (Na_2O)	0.84
Potassium Oxide (K_2O)	1.19
Moisture Content	-
Loss on Ignition	1.03
Specific Gravity	3.10

Table 3: Sieve analysis and physical properties of fine aggregate

	ASTM Sieve No.	Percentage Retained	Cumulative Percentage Retained	Cumulative Percentage Passing	ASTM Range (C 33)
Grading of Fine aggregate	16	30.97	30.97	69.03	50 - 85
	30	18.81	49.78	50.22	25 - 60
	50	37.49	87.27	12.73	5 - 30
	100	11.43	98.7	1.3	0 - 10
	Pan	1.28	-	-	-
Physical Properties of Fine aggregate	Unit weight (kg/m^3)	Bulk specific gravity (SSD)	Absorption (%)	Fineness Modulus	
	1698	2.48	0.96	2.45	

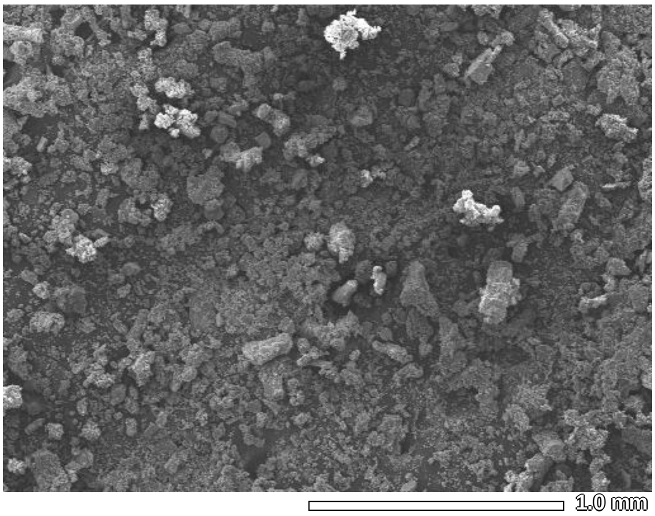

Figure 1: SEM micrograph of detergent

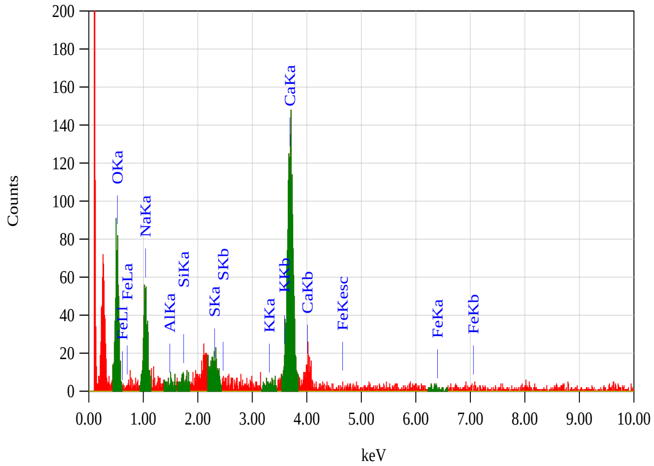

Figure 2: EDS plot of the detergent

Nomenclature of mixes

The mixes are divided into two categories designated as 'FA' and 'D' mixes. All mixes with designation of FA refer to control mixes, whereas the ones with designation D refer to foam concrete mixes produced using detergent as foaming agent. The nomenclature FA70C30S refers to control mix produced with foaming agent having 70% cement and 30% sand, by weight. Similarly, D70C30S refers to foam concrete mix produced with detergent used as foaming agent that has 70% cement and 30% sand by weight in it.

Manufacturing process

Required amount of water was first added into the foam concrete mixer followed by required dosage of FA or detergent. Mixer was allowed to run for about 2 minutes at its optimum speed till a uniform foam was created. Dry mix of cement and sand was then added simultaneously to the running mixer. Mixer was allowed to run for another 2 minutes till a uniform, flowing mix of foam concrete was achieved.

TEST RESULTS AND DISCUSSIONS

As-placed density

Table 4 shows the results of as-placed density of control and detergent mixes. In both control and detergent mixes, as-placed density increased with the increase in s/c ratio. For equivalent dosage, the as-placed density of control mixes was comparatively higher than that of the detergent mixes. This shows that at equal dosage there occurs more air-entrainment in case of detergent mixes. While the as-placed density for control mixes varied from 56 to 66 lb /ft^3, for detergent mixes, it varied over a range of 50 to 60 lb/ft^3. At equal dosage of air-entraining agent and cement-to-sand ratio the as-placed density of detergent mixes was found to be less than that of corresponding control mixes. This trend is thought to be the effect of higher percent of air entrainment (at equal dosage) in the case of detergent mixes as compared to control mixes. The trend of increase in the as-placed density with decrease in the cement-to-sand ratio was observed in both types of mixes. The average as-placed density of detergent mixes was found to be about 7% less than that of the control mixes.

Table 4: As-placed density test results

(a) Control mixes

Mix Designation	As-placed Density (lb/ft^3)
0.3FA70C30S	55.89
0.3FA65C35S	58.44
0.3FA60C40S	60.63
0.3FA55C45S	60.89
0.5FA70C30S	56.42
0.5FA65C35S	59.32
0.5FA60C40S	64
0.5FA55C45S	66.2

(b) Detergent mixes

Mix Designation	As-placed Density (lb/ft^3)
0.3D70C30S	53.17
0.3D65C35S	55.13
0.3D60C40S	57.68
0.3D55C45S	59.8
0.5D70C30S	49.6
0.5D65C35S	53.78
0.5D60C40S	57.75
0.5D55C45S	60.69

Oven-dry density

Results of oven-dry density are presented in Table 5. As in the case of as-placed density, oven-dry density of both control and detergent mixes also increased with a decrease in cement-to-sand ratio. Oven-dry density for control mixes varied from 43 to 54 lb/ft^3, for detergent mixes it varied from 41 to 53 lb/ft^3. Although on the basis of one-on-one comparison the oven-dry density of detergent mixes was found to be less than their corresponding control mixes, there was no significant difference between the average oven-dry densities of the two categories of mixes.

Table 5: Oven-dry density test results

(a) Control mixes

Mix Designation	Oven-dry Density (lb/ft^3)
0.3FA70C30S	48.89
0.3FA65C35S	50.94
0.3FA60C40S	52.13
0.3FA55C45S	53.89
0.5FA70C30S	42.62
0.5FA65C35S	43.38
0.5FA60C40S	45.19
0.5FA55C45S	47.12

(b) Detergent mixes

Mix Designation	Oven-dry Density (lb/ft^3)
0.3D70C30S	47.17
0.3D65C35S	49.13
0.3D60C40S	51.18
0.3D55C45S	53.08
0.5D70C30S	41.1
0.5D65C35S	45.28
0.5D60C40S	48.85
0.5D55C45S	51.89

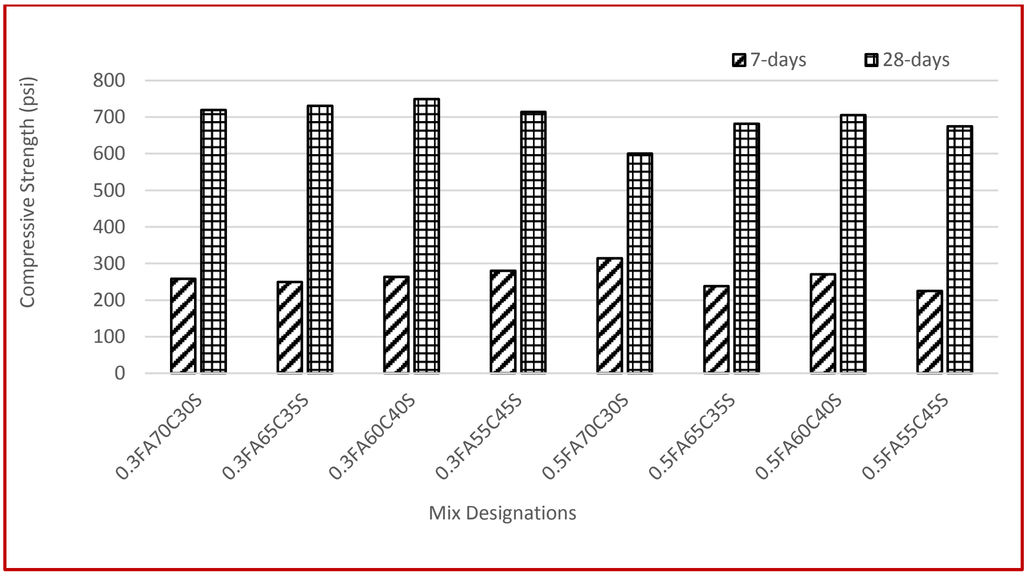

Figure 3: Compressive strength test results of control mixes

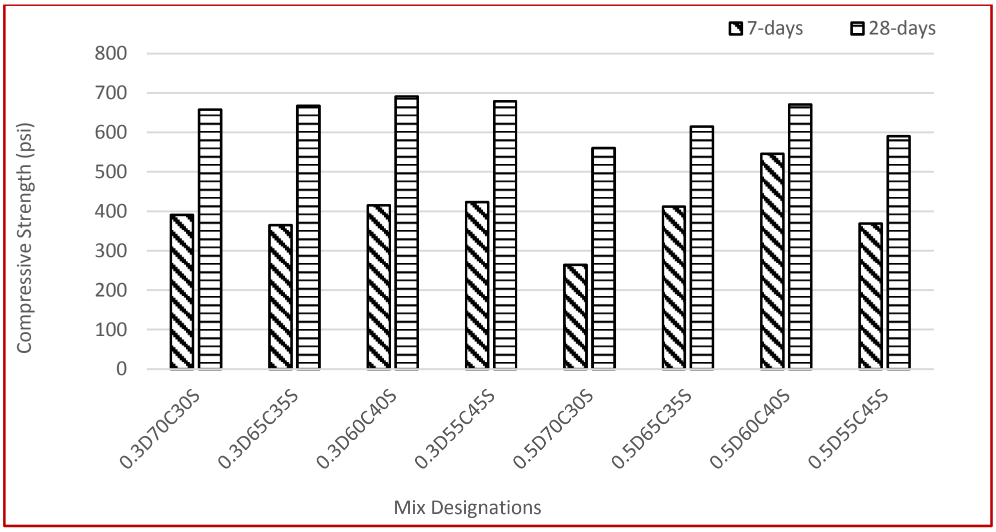

Figure 4: Compressive strength test results of detergent mixes

Compressive Strength

Results of 7 and 28 days compressive strengths are produced in figures 3 and 4 for the control and detergent mixes, respectively. Detergent mix designs produced higher 7-days strengths than the control mix designs. However, the 28-days compressive strength was higher in case of control mixes. This trend could be due to the fact that the strength development in control mixes tends to be slower than that of detergent mixes. Furthermore, the better evenly distributed structure of bubbles is responsible for comparatively high strength of control mixes than that of detergent mixes at 28-days. It is, however, to be noted that all the detergent mixes produced in this study produced a compressive strength well above the minimum requirement of 200 psi set by ASTM C 869 [17].

It was noted that compressive strength in almost all mixes started dropping as the cement-to-sand ratio approached 1.22. This is thought to be due to the leanness (amount of cement and sand approximately equals) of mix, in which the air-entrainment is not uniform, as observed from some of the specimens in hardened state. It can, therefore, be concluded that the compressive strength of foam concrete keeps on increasing with increase in density, however after a certain peak, the strength starts dropping, even if there is a corresponding increase in density. It is also clear from figures 3 and 4 that the compressive strength decreases with the increase in the dosage of air entraining agent in both categories of mixes.

The failure mechanism (cracks pattern) of foam concrete at 28-days compressive strength test was almost similar to that of normal mortar. This pattern of failure was, however, quite different in case of specimens produced with high dosage of air-entraining agent, in which case, at failure the specimens did not develop any cracks, rather, they compressed like soft compressible object till they were squashed.

Water absorption

Table 6 presents the results of the water absorption of the two categories of foam concrete mixes. Both categories of mixes with 0.5% dosage of corresponding air-entraining agent had double water absorption percentage when compared with corresponding mixes with 0.3% dosage of air-entraining agent. The water absorption in all mixes was found to increase with the increase in the dosage of air entraining agent while it decreased with the increase in the density of the mixes. For mixes with 0.3% dosage of air-entraining agent, the water absorption was within the limit set (less than 25% by volume) by ASTM C 869 [17]. Generally, detergent mixes were found to perform better at lower dosage of detergent; that is, they had less water absorption as compared to the corresponding control mixes.

Table 6: Water absorption test results

(a) Control mixes

Mix Designation	Water Absorption (% by weight)
0.3FA70C30S	24.01
0.3FA65C35S	22.62
0.3FA60C40S	21.34
0.3FA55C45S	20.9
0.5FA70C30S	40.45
0.5FA65C35S	38.09
0.5FA60C40S	37.45
0.5FA55C45S	37.34

(b) Detergent mixes

Mix Designation	Water Absorption (% by weight)
0.3D70C30S	21.62
0.3D65C35S	21.12
0.3D60C40S	20.09
0.3D55C45S	19.35
0.5D70C30S	45.75
0.5D65C35S	44.15
0.5D60C40S	43.07
0.5D55C35S	42.86

Few of the 2-inch cube specimens in moisture saturated conditions were broken to observe their inner structure. It was found that, water, actually did not penetrate to the core of the specimens, it was rather confined to the outer most layer of the specimens. The outer shell being not strong enough to hold all the air bubbles, becomes porous and hence susceptible to water penetration. In the core structure of foam concrete, the air bubbles discontinue the capillaries and hence water penetration is inhibited. This is thought to be principal reason of high durability of air-entrained concretes, especially foam concrete. The above-mentioned fact also substantiate as to why foam concrete has lower rate of water penetration [1].

Thermal conductivity

Concrete disc specimens in semi-saturated moisture condition were used for the thermal conductivity test using the Transient Plane Source (TPS) method at 28 days of concrete age. Figure 5 shows the schematics of the TPS based test arrangement of thermal conductivity test. As shown in the figure a hot disc sensor is sandwiched between concrete specimens. This sensor acts as heat source as well as resistance thermometer or temperature sensor. When a heating pulse is applied from an electric source, the temperature of sensor rises and flow of heat starts to the in-contact foam concrete discs. The temperature rise in the sensor is a direct measure of the thermal conductivity of the in-contact concrete specimens. If foam concrete has low thermal conductivity, there will be rapid rise in the sensor temperature once heating effect is applied. On the other hand, if the in-contact foam concrete has good thermal conductivity, the heat generated shall quickly transport inside. Thermal conductivity tests were carried out on the foam concrete mixes produced with 0.3% dosage of air-entraining agents in both categories of mixes. Table 7 presents the results of thermal conductivity tests for various mixes. A linear relationship was observed between thermal conductivity of foam concrete and its oven dry density. While the thermal conductivity was found to increase with a decrease in the cement-to-sand ratio in both categories of mixes, no significant difference in thermal conductivity of the two categories of mixes was recorded.

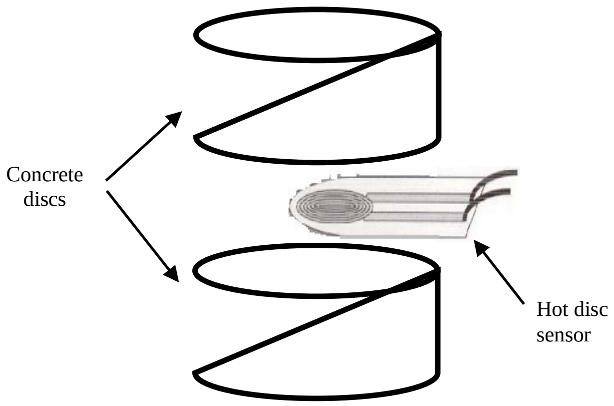

Figure 5: Schematics of the TPS method of thermal conductivity test

Table 7: Thermal conductivity test results

(a) Control mixes

Mix Designation	Thermal Conductivity BTU/(hr.ft.ºF)
0.3FA70C30S	0.13
0.3FA65C35S	0.13
0.3FA60C40S	0.14
0.3FA55C45S	0.14

(b) Detergent mixes

Mix Designation	Thermal Conductivity BTU/(hr.ft.ºF)
0.3D70C30S	0.13
0.3D65C35S	0.14
0.3D60C40S	0.14
0.3D55C45S	0.14

Cost analysis

Cost analysis of the two types of foam concretes (control and detergent based) was carried out based on the prevailing market prices of the materials. The mixes selected for comparative cost analysis were those which showed highest compressive strength and had shown optimum performance in the oven dry density and water absorption tests. Detailed cost analysis are shown in Table 8. Based on these cost analysis, 0.3D60C40S was found to be 42.57 per cent cheaper than 0.3FA60C40S.

Table 8: Cost comparison analysis

Material	Rate per 0.5ft^3 (PKR)	Control Mix (0.4FA60C40S)		Detergent Mix (0.4D60C40S)	
		Quantity (per 0.5ft^3)	Amount (PKR)	Quantity (per 0.5ft^3)	Amount (PKR*)
Cement	18	42.84	771	42.84	771
Sand	0.305	57.2	17.5	57.2	17.5
FA	1098	0.55	604	-	-
Detergent	105	-	-	0.103	11
Total	-	-	1,393	-	799.5
Percent reduction in cost = 42.57					

*Pakistani Rupees

CONCLUSIONS

Based on the experimental results, following conclusions are drawn:

- The production of low-cost foam concrete using locally produced detergent as replacement of commercially available FA is a feasible practice.
- Strength and durability characteristics of foam concrete mixes produced with detergent as foaming agent are quite comparable to that of control foam concrete mixes produced with FA as the air-entraining agent.
- Foam concrete mix produced with a dosage of detergent at the rate of 0.3 per cent by weight of cement, having cement-to-sand ratio of 1.5 was found to be the optimum mix design. This mix design exhibited excellent mechanical properties meeting the relevant acceptable ranges.
- Market based cost analysis showed that mix designation 0.3D60C40S was 42.57 per cent cheaper as compared to its corresponding control mix 0.3FA60C40S.
- The results of the study are encouraging and various properties of the foam concrete produced with detergent as air-entraining agent can be further improved by fine-tuning the mix proportioning.

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